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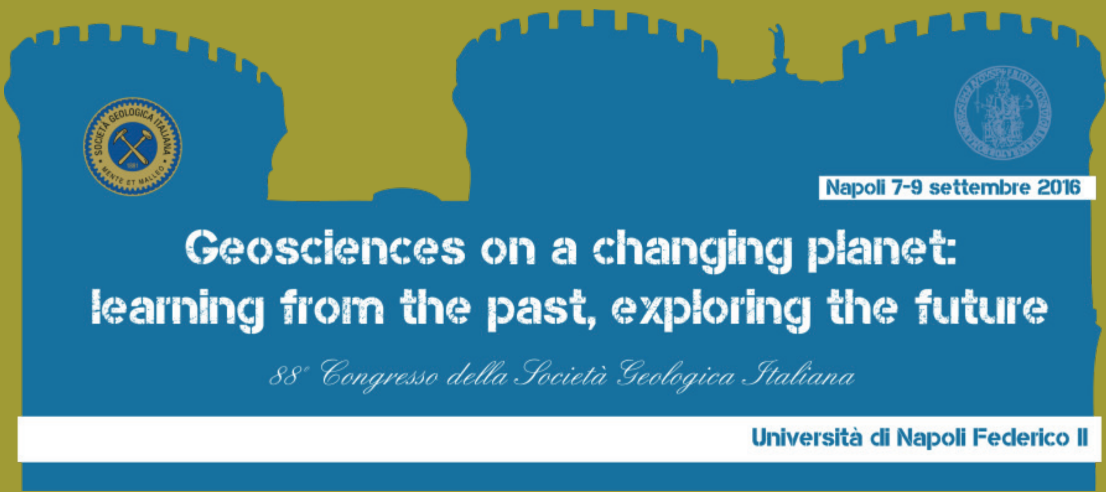
Geosciences on a changing planet: learning from the past, exploring the future

88° Congresso della Società Geologica Italiana

Napoli 7-9 Settembre 2016



Abstract book

Edited by

D. Calcaterra, S. Mazzoli, F.M. Petti, B. Carmina & A. Zuccari

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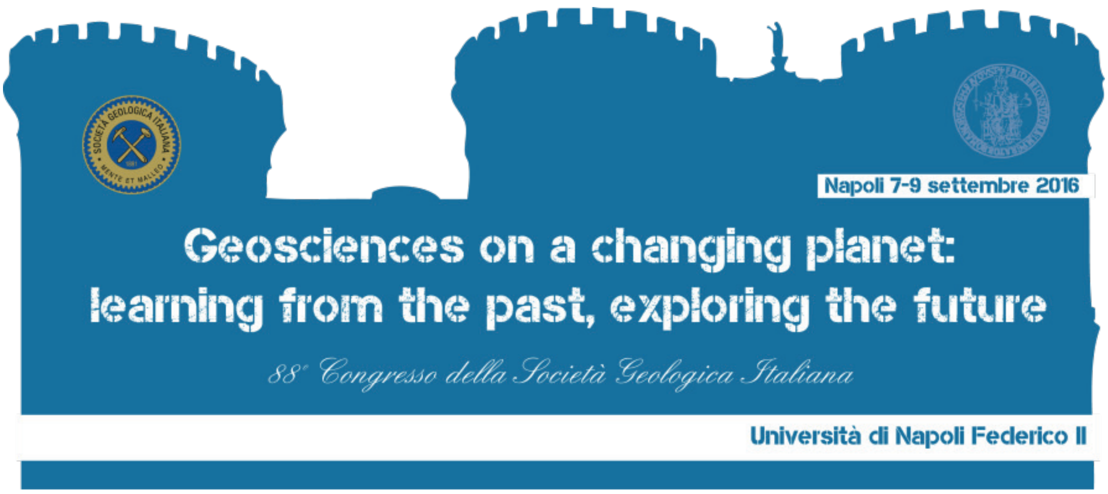

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SUMMARY

In coda al volume elenco alfabetico dei riassunti per Session ed elenco degli autori.

PLENARY LECTURES

Recovery from the greatest mass extinction of all time

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Keywords: end-Permian mass extinction, biotic recovery.

The aftermath of the great end-Permian mass extinction, 252 million years ago, shows how life can recover from the loss of >90% species globally. The initial causes of the catastrophe continued to devastate Early Triassic environments and slowed the biotic recovery. Huge attention is currently focused on the exceptional Permo-Triassic rock successions in China, which document the recovery step-by-step. In addition, novel phylogenetic-macroevolutionary methods are being applied to this greatest-of-all 'adaptive radiations'. How did the successful post-extinction clades respond to the opportunity, and build up the fundamentals of modern ecosystems?

Benton M.J., Forth J. & Langer M.C. 2014. Models for the rise of the dinosaurs. Current Biology 24, R87-R95, doi:10.1016/j.cub.2013.11.063.

Benton M.J., Zhang Q.Y., Hu S.X., Chen Z.Q., Wen W., Liu J., Huang J.Y., Zhou C.Y., Xie T., Tong J.N. & Choo B. 2013. Exceptional vertebrate biotas from the Triassic of China, and the expansion of marine ecosystems after the Permo-Triassic mass extinction. Earth-Science Reviews. 123, 199-243, doi:10.1016/j.earscirev.2013.05.014.

Chen Z.Q. & Benton M.J. 2012. The timing and pattern of biotic recovery following the end-Permian mass extinction. Nature Geoscience 5, 375-383, doi:10.1038/ngeo1475. University of Bristol: http://palaeo.gly.bris.ac.uk/PTB/

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Atmospheric Oxygen and Biological Evolution

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Keywords: Atmospheric oxygen, biological evolution.

More than any other element, oxygen shapes the current biosphere. It is produced by photosynthesis and it is used to respire most of the organic matter at the Earth surface. However, this is not always been the case. During the first 2 billion years of Earth history, oxygen concentrations were likely over 100,000 times less than present levels. Could an aerobic biosphere have existed with so little oxygen? This question is addressed through growth experiments conducted on E. coli utilizing special oxygen sensors with ultra-low oxygen-detection limits. We find that E. coli can grow and respire oxygen at oxygen concentrations < 2nM which is 100,000 times less than found today in air-saturated water. After about 2.4 billion years ago, oxygen concentrations rose to levels that are uncertain. There is a prevailing view, however, that these levels were insufficient to allow respiration by animals thus preventing their evolution. The minimum levels of oxygen required for animals (as a group), however, is poorly known. We attempt to define the levels required for animal respiration through a variety of respiration and behavior experiments on two different marine sponges. We show that sponges feed and respire at oxygen concentrations ranging between 1 and 4% of present levels. This, therefore, might be viewed as a possible minimum oxygen requirement by early animals. We provide further evidence from the Xiamaling Formation in China to show that atmospheric oxygen may have attained these levels well before animals, implying that other factors controlled the timing of animal evolution.

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In memory of Marco Beltrando

Dal Piaz G.V.[1] & Manatschal G.[2]

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Keywords: Marco Beltrando, Western Alps.

Six months have already passed since December 8th 2015, when, at the age of 36, Marco Beltrando died in an accident in the Western Alps, suddenly leaving his beloved family, relatives and friends. After the tribute to his memory during the EGU Assembly, this SGI Congress reminds us again of Marco Beltrando, addressed in particular to those geologists who did not have the good fortune to know him personally. Time passes quickly, but the memory of such a special young person is still vivid, always cheerful and smiling, although reserved, sincere and generous. Marco was an enthusiastic, curious and brilliant geologist who was especially fascinated by the geological puzzle of the Western Alps and the process required to unravel it back to the complex rifting stage. He also loved the mountains themselves and mountaineering - hiking and climbing during the summer, and cross-country skiing in winter. Marco spent some time as a student at the University of Utrecht, and graduated in Geology at the University of Turin in 2002. He then achieved his PhD at the Research School of Earth Sciences of the Australian National University in Canberra in 2007. On his return to Italy, he worked as a researcher in the Structural Geology Group of the University of Turin, where he taught Structural Geology and Regional Geology of the Alps, and trained many MSc and PhD students working with him. Only four days before his death, Marco had been granted tenure as Associate Professor at the University of Turin (December 4th 2105). He wrote: “My main research focus lies in the field of tectonics, in both convergent and divergent settings. I address large-scale geodynamics through a combination of structural field geology, microstructural analysis, petrography and geochronology. The main questions I am currently addressing range from the tectono-metamorphic evolution of hyper-extended rifted margins, to the influence exerted by rift-inherited hyper-extension on the evolution of orogenic belts”. In particular, he was able to integrate these modern field and laboratory techniques harmoniously in a modern approach, successfully applied to elucidate the paleo-structural setting of a very complex tectono-metamorphic wedge and a fossil subduction zone, including mantle slices within continental to oceanic basement and cover units, and also to develop new ways of thinking about extensional and collisional systems. In both these large fields, he was at the forefront of research, as highlighted by his innovative contributions and many invitations to international conferences. We last saw Marco during his last lecture (recorded), given in Venice at the meeting “Geologia delle Alpi”. In Marco, we do not only lose a great colleague, an outstanding researcher and a very good teacher, but also a dear friend.

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Climate change: how can information from the past inform the future?

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Keywords: Paleoclimate, Earth's history.

During the last decades, curiosity-driven research has continuously explored all dimensions of past climate variations, using a wide variety of natural archives, proxies, methods and models, forming a major collective endeavour. Beyond uncertainties, challenges and unresolved issues, solid knowledge is gradually built about the causes, mechanisms, amplitudes and rates of past natural changes, at regional to global scales, and throughout Earth's history. The study of past climates benefits from modern in situ and remote sensing observations, process studies, and the development of climate models to Earth system models: improved knowledge of present-day climate is crucial to understand the proxies used for paleoclimate reconstructions, and numerical models provide a solid basis to test the plausibility of hypotheses and theories relating potential causes and mechanisms of past changes, and to understand large-scale processes affecting local records. There is no past analogue to the magnitude and rate of human perturbations to the global climate system, and, given the non-linear nature of the climate system, future changes cannot be predicted from an interpolation of recent trends: future changes can only be explored using comprehensive models, based on physical principles, providing ensemble projections of future changes in response to various scenarios of human perturbations. Nevertheless, the same climate system has reacted, in the past, to a variety of natural perturbations of geological or astronomical origin, and has produced internal variability. These past changes can therefore be seen as "natural experiments" on the Earth's system. In this respect, information from the past is first crucial to complement short instrumental or remote sensing records. This is particularly true for difficult-access areas such as polar regions or deep oceans, where paleoclimate records fill modern observational gaps. Long records can inform whether recent changes are part of natural climate variability, or unusual. Moreover, paleoclimate information is crucial to characterize the full range of natural climate variability and associated impacts, including abrupt change, and to assess the magnitude and timescales of response of the climate system to perturbations of the Earth's radiative budget and inform on key issues such as climate sensitivity, or ice sheet vulnerability to polar warming. Finally, information from the past is critical to benchmark climate and Earth system models, which are the only tools that can inform the future. Methodologies are being developed to compare outputs from climate models with paleoclimate data, accounting for uncertainties in model boundary conditions, and uncertainties on magnitude and timing of past changes, sometimes including explicit proxy modelling. While most of these comparisons were so far performed for "steady state", considering the climate response "at equilibrium" (testing whether climate models can produce the right magnitude of responses), new developments are emerging to assess the ability of climate models to resolve the transient aspects of past changes (testing whether climate models can produce the right rate of changes). Given the spread of climate model results for future projections, taking advantage of past climate knowledge may help to identify subsets of models that perform better for a given mechanism, complementing evaluation of models for present-day, and therefore reduce uncertainties on future projected changes. Key questions related to understanding past changes on a variety of timescales are therefore also relevant for future changes and will be illustrated during this presentation.

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The Interdependence of Plate Coupling Processes, Subduction Rate, and Asthenospheric Pressure Drop across Subducting Slabs

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Keywords: plate coupling, astenospheric pressure, subduction rates.

One advantage of analytical models, in which analytic expressions are used for the various components of the subduction system, is the efficient exploration of parameter space and identification of the physical mechanisms controlling a wide breadth of slab kinematics. We show that, despite subtle differences in how plate interfaces and boundary conditions are implemented, results for single subduction from a 3-D semi-analytical model for subduction FAST (Royden & Husson, 2006; Jagoutz et al., 2015) and from the numerical finite-element model CitcomCU (Moresi & Gurnis, 1996, Zhong et al., 2006) are in excellent agreement when plate coupling (via shear stress on the plate interface) takes place in the FAST without the development of topographic relief at the plate boundary. Results from the two models are consistent across a variety of geometries, with fixed upper plate, fixed lower plate, and stress-free plate ends. When the analytical model is modified to include the development of topography above the subduction boundary, subduction rates are greatly increased, indicating a strong sensitivity of subduction to the mode of plate coupling. Rates of subduction also correlate strongly with the asthenospheric pressure drop across the subducting slab, which drives toroidal flow of the asthenosphere around the slab. When the lower plate is fixed, subduction is relatively slow and the pressure drop from below to above the slab is large, inhibiting subduction and slab roll-back. When the upper plate is fixed and when the plate ends are stress-free, subduction rates are approximately 50% faster and the corresponding asthenospheric pressure drop from below to above the slab is small, facilitating rapid subduction. This qualitative correlation between plate coupling processes, asthenospheric pressure drop, and rates of subduction can be extended to systems with more than one subduction zone (Holt et al., 2015 AGU Fall Abstract).

Jagoutz O., Royden L., Holt A. & Becker T.W., 2015. Anomalously fast convergence of India and Eurasia caused by double subduction. Nature Geoscience 8, 475-478, doi:10.1038/NGEO2418.

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Zhong S. 2006. Constraints on thermochemical convection of the mantle from plume heat flux, plume excess temperature, and upper mantle temperature. Journal of Geophysical Research, 111, doi: 10.1029/2005JB003972.

Tra Scilla e Cariddi: communicating geology to the public

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Keywords: public communication, geoscience.

Geoscientific knowledge and understanding lies at the heart of many of the most critical societal issues that face us in the 21st century. The pressing human challenges of natural disaster reduction, energy supply and security, and mineral and water resource management, rest on geological foundations. And yet, outside of the academic and industrial geoscience community there is a limited appreciation of Earth Science, especially among policy makers. Geology, it seems, lies out of sight and out of mind. For that reason, geologists are increasingly being encouraged to communicate more broadly what they do and what they know. Yet how can we do that when, for most people, geology is about 'stones' and stones are 'boring'! It is a problem compounded by the fact that many of our most acute geo-issues are rooted in the unfamiliar realm of the 'deep' subsurface. This talk will use the experience of popularising geoscience for mainstream television to explore ways in which geologists can make our research connect better with the dissonant public, and in doing so forge more effective strategies for public communication.

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Changes in River Network Geometry and Implications for Landscape Evolution over Geologic Timescales

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Keywords: river networks, tectonic processes, geomorphic processes.

The map pattern of river networks has always held great promise for providing information about tectonic and geomorphic processes on the Earth's surface, but we have never had the tools or the conceptional framework to exploit this information. One of the fundamental characteristics of river networks, potentially serving as the basis for an interpretative framework, is the observation that drainage area and channel slope tend to scale at all points in a river network. If this condition represents an equilibrium state of a river network, deviations from this state can be interpreted in terms of tectonic or climatic perturbations. This is easier to visualize through the integral form of this relationship, which predicts a linear relationship between elevation of a point in a channel network and the downstream integral of the drainage area, a quantity now commonly referred to as x. A spatial map of x quickly and clearly shows patterns that can be interpreted in terms of landscape disequilibrium, demonstrating where and how the geometry and topology of a river network is adjusting through divide migration or river capture. Maps of x are easily constructed using modern GIS methods and commonly available digital elevation models. I present several examples in this talk of mountain belt or continental-scale river reorganization on-going in response to tectonic forcing. The first example is the Danube river basin in central Europe. The Danube represents the last vestiges of the Tethys Ocean, north of the Alps, and its successor, the North Alpine foreland basin. The closure of the Tethys is continuing into the modern era with the drainage basin of the Danube showing collapse and loss of drainage area with advance of the water divides from the Rhine and Adriatic drainages into the Danube. We interpret this as the natural response to ocean closure and isostatic rebound of the foredeep, as well as retreat of baselevel for the Alpine rivers from the former marine foredeep to the modern Black Sea. A second example is presented from the Great Plains of North America, where the subduction-related, mid-continent seaway retreated at the end of the Cretaceous leaving the Mississippi river basin between the Rockies and the Appalachian mountains. In the late Miocene, the Rockies experienced a period of dynamic uplift related to the motion of North America over a mantle upwelling north of the East Pacific Rise. This renewed sedimentation into the Rockies foreland with the deposition of the Ogallala group, which served to completely resurface the High Plains physiographic province and, at its peak extent, covered more than half a million square kilometers. Today we are witnessing the establishment of a new river network incising into the Miocene alluvial fan surface. This is evident in the dissection of the Ogallala units, with isolated erosional remnants being consumed by surrounding rivers as they integrate parallel, fan-face channels into dendritic basins. Finally, I present an example from the active orogenic belt of Taiwan, where rapid uplift has produced short, steep catchments in uniform lithology competing laterally for drainage area. I present evidence for various modes of catchment area exchange, including river capture, tributary stripping and steady divide migration. Processes are confirmed by differential erosion rates measured with concentrations of cosmogenic 10Be.

SESSION S1

Earthquakes and Active Tectonics: a multidisciplinary approach

CONVENERS AND CHAIRPERSONS

Claudio Chiarabba (INGV-Roma1)
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Paolo Galli (Dipartimento Protezione Civile)
Aldo Zollo (Università di Napoli Federico II)

How many information can be retrieved by applying a multidisciplinary approach to investigate a seismic sequence? Case studies from Italian region

Adinolfi G.M.[1], De Matteis R.[2], Festa G.[1], Zollo A.[1], de Nardis R.[3-4], Ferrarini F.[3], Brozzetti F.[3], Cirillo D.[3] & Lavecchia G.[3]

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Keywords: Multidisciplinary approach, Seismotectonics, Benevento earthquake, L'Aquila earthquake.

Acquiring information with an adequate accuracy is a difficult task when low-magnitude earthquakes occurring and when blind or buried structures are activated. In these cases, the full integration of geological/geophysical and good-quality instrumental data is necessary to constrain the 3D shape and size of seismogenic segments, as well as their kinematics. Improvements in the knowledge and characterization of seismogenic faults are required, also exploring additional sources if they exist.

For such purpose, we propose a multidisciplinary methodological approach that full integrates seismological, structural and geodynamic data. After re-locating earthquakes (absolute and relative techniques), we carry out a complete kinematic rupture analysis inverting data for the moment tensor, retrieving apparent source time functions and providing kinematic source models by back-projection method. Then, we collect existing field data, geological and macroseismic ones, if they are available. These data are also integrated with sub-surface records provided by the examination of accessible seismic lines and well data. Finally, the reconstruction of the active and long-term, local and regional, tectonic framework is achieved. The results of the two previous steps are combined defining the seismotectonic link of the recovered seismogenic faults with regional tectonic lineaments.

This methodology of analysis was performed on two case studies of the recent Italian seismicity: the small 2102 strike-slip sequence, occurred near Benevento at depths of 16-20 km, and the strongest aftershock (Mw 5.5) of the 2009 L'Aquila extensional seismic sequence, occurred at depth of about 14 km.

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The 2013, ML 4.9, Matese earthquake (Southern Apennines, Italy): a normal faulting earthquake at an anomalous depth

Adinolfi G.M.[1], De Matteis R.[2], Zollo A.[1], Ascione A.[3] & Mazzoli S.[3]

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Keywords: Multidisciplinary approach, Seismotectonics, Matese earthquake.

At the end of December 2013, a Ml 4.9 earthquake struck the Matese region in Southern Apennines. The Matese Mountains fall in the epicentral area of strong historical earthquakes, the most destructive with X-XI Mercalli-Cancani Sieberg (MCS) intensities occurred in 1456, 1688 and 1805 and caused thousands of casualties. Considering the high seismic hazard, the 2013 Matese earthquake had soon aroused great interest into the scientific community. Several essential questions are still unresolved about the anomalous depth (> 15 km) for the area expected seismicity, the real geometry of the activated seismogenic source and its role into the regional seismotectonic setting.

Focusing seismological analyses on the mainshock, we have relocated the earthquake and constrained its depth verifying several crustal velocity models. Moreover, we have calculated the moment tensor solution and assessed the depth range of the best solution as independent test for the hypocenter depth. Then, we have explored the rupture process calculating the Apparent Source Time Functions (ASTFs) and inverting them by isochrone back-projection to obtain a kinematic slip map. Integrating seismological analyses with geological data, we have delineated the seismogenic source addressing question about: a) the geometry of the fault plane over which the Matese mainshock occurred; b) the real depth at which the activated fault plane extends and the crustal extensional deformation is active in Southern Apennines and c) a potential rheological model for the Matese seismogenic fault and its difference with the known active faults.

Integrated monitoring system GB-InSAR and Terrestrial Laser Scanner for Mont de La Saxe landslide, Italy

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Keywords: La Saxe Early Warning Radar, TLS laser scanner, rockslide, landslide.

A careful description of the failure mechanisms is fundamental for the understanding of landslide evolution and a quantitative hazard analysis, assessment and mitigation.

A complete kinematic characterization of the landslide ground surface allows to attain a description and zonation in terms of displacement and deformation paths. A robust and complete displacement field might be obtained by correlating a series of multi-temporal observations performed by means of terrestrial laser scanning and ground-based interferometric radar surveys.

We investigate the Mont de La Saxe landslide (8 million m^3, Aosta Valley Region, northern Italy), on the left-hand side of Ferret Valley within a deep-seated gravitational slope deformation. This landslide is one of the most investigated and monitored in the European Alps. A complete monitoring dataset exists since 2009. Because of its location just above Entreves and La Palud villages and its proximity to the Mont Blanc highway tunnel and to the Mont Blanc cableway, this landslide poses an extremely high risk.

The evolution of the ground surface displacements is monitored by means of optical targets, a fixed and time-lapse GPS network, a ground-based interferometer and periodic Terrestrial Laser Scanner surveys. Distribution of displacements at depth is monitored by multi-parametric borehole probes (2D-DMS columns) and borehole wire extensometers.

In this contribution we discuss the advantages of the comparison and mutual integration of ground-based radar interferometric data (daily-acquired) and Terrestrial Laser Scanner data (monthly-acquired). Therefore, the comparison is performed between a monitoring system, characterized by a high-accuracy (millimetric), near real-time monitoring capability and with no morphological information (i.e. GB-InSAR), and the TLS system, characterized by low-accuracy (centimetric) with a laborious post-processing but with an important morphological content. In particular, we use this data to analyze the temporal evolution of the landslide during the last 3 years with a main focus on the April 2014 crisis (max displacement rate of ca. 1000 mm/day).

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High resolution 3D imaging of the Irpinia active fault zone

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Keywords: Irpinia, Seismic tomography, seismic velocity, seismic attenuation, rock physics modeling, fluids

Seismic tomography allows reconstructing images of the subsurface elastic/anelastic properties, and may provide insights on the physical conditions of the investigated medium. These conditions are relevant for complex fault structures like the Irpinia fault zone. The 3D delay time tomography of Amoroso et al. (2014) showed the presence of a high Vp/Vs rock volume including the hypocenter of the 1980 Irpinia earthquake and the recent microseismicity. This result was interpreted in terms of the presence of permeating fluids.

On the base of this interpretation we performed a 3D attenuation tomography using the P and S reduced travel time (i.e., the ratio of the slowness over the quality factor Q) data provided by Zollo et al. (2014) for about 700 earthquakes occurred in the area recorded by the Irpinia Seismic Network (ISNet). Results show that Qp increases up to 1000 between 8 and 10 km depth inside a volume spatially correlated with the Irpinia earthquake fault structure. Qs shows different characteristics, being more sensitive to the structural setting.

Then we performed an up-scaling approach to predict the expected seismic velocity and attenuation for a given host rock characterized by a set of micro-parameters (porosity, percentage of fluid saturation and permeating fluid type) (Dupuy et al., 2016). The up-scaled values were then compared with those inferred from the velocity and attenuation tomography. We focused our modeling on the volume where Qp reaches the largest values. we assumed a dolomitic composition of the host rock, with the consolidation parameter (Cs) varying in the range [5.5 7.5], and porosity in the range [0%, 5%]. Pores are assumed to be filled by a two-phase fluid.

Results show that even using Cs=7.5, the corresponding porosity is [3%,5%], much larger than those expected for carbonate rocks at that depth. Also, all the explored fluid mixing couples are plausible. We then confirm

the interpretetion of Amoroso et al. (2014), and propose that hydraulic fracturing and fluid overpressure contribute to create and preserve a significant amount of fracture porosity at depth. We suggest that the triggering mechanism of seismicity occurring in the Irpinia fault zone is strongly controlled by the presence of fluid phases, which induces a pore pressure increase in the saturated and highly fractured medium.

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Geology of the Piedimonte Matese-Gioia Sannitica active normal fault (southern Matese Mountains, Italy)

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Keywords: Earthquakes, Apennine, Matese.

The 2013–2014 Matese seismic sequence (Ml 4.9 main event on December 29 2013) has renewed interest on the Matese massif, highlighting the seismic hazard of the entire Sannio-Matese area, struck by at least 5 destructive earthquakes during the last 1700 years. Moreover, GPS data show very high extension rates across the Matese (2-3 mm/yr) (Giuliani et al., 2009). Only two fault systems in northern Matese were associated to strong historical earthquakes: the Isernia-Bojano-Guardiaregia and the Pozzilli-Capriati al Volturno (Aquae Iuliae) normal faults (Di Bucci et al., 2005 cum bibl.; Galli & Naso, 2009). Recently, a new model for segmentation pattern of active faults in the Matese area has been proposed (Boncio et al., 2016). However, a lack of geological data characterize the south-eastern side of the massif between Piedimonte Matese and San Salvatore Telesino.

We present original field data from geologic mapping, bedrock structural geology and detailed topographic profiles along the ~18 km-long, SW dipping Piedimonte Matese-Gioia Sannitica normal fault (PMGSF). For the first time we provide evidence of Late Quaternary activity of this fault. The fault displaces fan gravels with interlayers of leucite-free, trachytic tuffs younger than the first cycle of the Roccamonfina volcano (younger than 350 ka ago) and colluvial/soil deposits of Holocene radiocarbon age (datings on bulk samples). Topographic profiles of fault scarps suggest post-LGM throw rates of 0.1-0.34 mm/yr.

The geology of the PMGSF and its relationship with the surrounding faults recently identified along the western side of the Mates mountains (APMF and GLMLF, Boncio et al., 2016) allowed us to suggest that the fault system along the southern side of the Matese mountains are the plausible sources of poorly-known historical destructive earthquakes, such as the 346/355 AD, 847 and 1293 Matese earthquakes.

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Width of the surface rupture zone for thrust earthquakes and implications for earthquake fault zoning: Chi-Chi 1999 and Wenchuan 2008 earthquakes

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Keywords: Surface fault rupture hazard, thrust earthquake.

We analyze the characteristics of the zones of coseismic surface faulting along thrust faults, whit the aim of defining the most appropriate criteria for zoning the Surface Fault Rupture Hazard (SFRH) along thrust faults. Normal and strike-slip faults were deeply studied in the past concerning SFRH, while thrust faults have not been studied with comparable attention.

We analyzed the 1999 Chi-Chi, Taiwan (Mw 7.6) and 2008 Wenchuan, China (Mw 7.9) earthquakes. Several different types of coseismic fault scarps characterize the two earthquakes, depending on the topography, fault geometry and near-surface materials (simple and hanging-wall-collapse scarps; simple, oblique, back-thrust and low-angle pressure ridges; fold scarp; local normal fault scarp). For both the earthquakes, we collected data about the Width of the coseismic Rupture Zone (WRZ), measured perpendicularly to the trace of the main fault. WRZ data were compiled from the literature or measured in GIS-georeferenced published maps.

The frequency distribution of WRZ compared to the trace of the main fault shows that the surface ruptures occur mainly on and near the main fault. Ruptures located away from the main fault occur mainly in the hanging wall. Where structural complexities are present (e.g., sharp bends, step-overs), WRZ is wider then for simple fault traces. We also fitted the distribution of the WRZ dataset with probability density functions, in order to define a criterion to remove outliers (e.g., by selecting 90% or 95% probability) and define the zone where the probability of SFRH is the highest. This might help in sizing the zones of SFRH during seismic microzonation (SM) mapping.

In order to shape zones of SFRH, a very detailed earthquake geologic study of the fault is necessary (highest level of SM, i.e., Level 3 SM according to Italian guidelines). In the absence of such a very detailed study (basic SM, i.e., Level 1 SM of Italian guidelines), a width of 350-400 m seems to be recommended (95% of probability). For higher level SM, where the fault is carefully mapped, one must consider that the highest SFRH is concentrated in a narrow zone, ~ 50 m-wide, that should be considered as a "fault-avoidance (or setback) zone" (equivalent to the "Zona di Rispetto" of the Italian guidelines). These fault zones should be asymmetric compared to the trace of the main fault. The ratio of footwall to hanging wall (FW:HW) calculated here ranges from 1:5 to 1:3.

Our results appear to be reasonable for thrust faults, but must be considered preliminary as they rely on two earthquakes only, and a larger number of case studies is necessary for a generalized applicability.

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The 847 AD earthquake: historical sources and archeoseismological indications from the Matese-Volturno area (central-southern Italy)

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Keywords: archaeoseismology, 847 AD earthquake, central-southern Italy.

Information on past earthquakes is largely derived from historical written sources, whose interpretation in the seismological perspective constitutes the basis of the modern seismic catalogs. However, due to the scarcity of historical sources, the knowledge on the seismic history of Italian peninsula from the Late Antiquity to the Middle Ages can only be improved through the use of other investigation methods (e. g. archaeological and paleoseismological). Archaeoseismological investigations are focused on the identification of evidence of past earthquakes on ancient buildings, structures discovered during archaeological excavations or in still standing monumental buildings. The main questions to be answered by archaeoseismological investigations are: (1) how probable are seismically induced ground motion or secondary effects as the cause of damage observed in ancient man-made structures? (2) when did the damaging ground motion occur? and (3) what can be deduced about the nature of the causing earthquake? In any case, it should be emphasized that a correct characterization of the archaeoseismological evidence coming from archaeological methods and data must be integrated with those inferred from geological, geophysical, geotechnical, engineering-structural analysis and with historical and seismological information.

In this contribution, we attempt to broaden the knowledge on the 847 AD earthquake that struck central-southern Italy (northern Campania, Molise and Latium) through a critical review of historical written sources and archaeological evidence useful to characterize the effects of this earthquake. The archaeoseismic evidence is relative to oriented collapse in the Abbey of St Vincenzo al Volturno (IS), while in the basilica of Alvignano (Volturno plain south of Matese mountains, CE) still standing deformed pillars can be observed. For the area of Isernia, unfortunately, archaeological data relative to destruction and following reconstruction of buildings have not been found; conversely historical sources report total destruction of the town. Although historical sources did not explicitly mention damage in Roma, the traces of the 847 AD earthquake have been largely documented in the archaeological and seismological literature. Starting from the earthquake shaking nature, a wide area of damage effects has been defined in northern Campania, Molise, and Latium, an area of still intense geodetic strain accumulation but with limited characterization of active structures.

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Veining and post-nappe transtensional faulting in the SW Helvetic Alps (Switzerland)

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Keywords: Alps, Faults, Veins, Transtension, Brittle-ductile transition, Seismic activity.

In the Rawil Depression of the south-western Helvetic Alps, oblique (normal plus dextral strike slip) faults are common but their relative age, regional role and the processes leading to their development are not yet fully determined. This field study establishes the orientation and distribution of these faults and associated veins, the fault geometries and kinematics, and the relationship between veining and faulting. Three post-nappe sets of faults can be distinguished on the basis of their strike: (1) NNW/NW-striking; (2) WNW/W-striking; and (3) WSW-striking ones. Faults sets (1) and (2) generally dip at moderate angle to the SW and typically develop domino-like structures, with a spacing of around 1 km. Fault set (3) is steeper, the strike-slip component is larger, and it is directly associated with the main regional-scale branch of the Simplon-Rhône Fault. Although these faults are broadly coeval, there are clear examples of set (2) crosscutting set (1), and set (3) crosscutting (1) and (2), which establishes, at least locally, a relative chronological succession. This transtensional faulting largely post-dates folding related to nappe formation because fold geometry can be matched across the obliquely crosscutting faults. Regional dextral-transtensional fault development is related to differential exhumation of the External Crystalline Massifs over the last 15-17 Ma, coeval with related movement on the Simplon-Rhône Fault. Locally there is a transition from an initial more ductile mylonitic fabric to cataclasite, accompanied by brittle-ductile veining and intense pressure solution. This progressive embrittlement during faulting is due to exhumation and cooling during faulting, higher strain rates, or increased pore-fluid pressures. Faults of sets (1) and (2) developed across the brittle-ductile transition and may represent fossil seismogenic zones in rocks with high pore-fluid pressure, providing exposed examples of seismic faults in similar rocks currently active at depth north of the Rhône valley.

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Meso- and macroscale analysis of an ancient analogue of a shallow megathrust

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Keywords: megathrusts, Sestola-Vidiciatico Unit (SVU), soft sediment deformation, shear surfaces.

Megathrusts are characterized by a spectrum of slip behaviour, including large earthquakes, tsunami earthquakes, slow slip and tremors. The mechanisms controlling such complex behaviour are still poorly understood, also because of the inaccessibility of active megathrust faults.

The Sestola-Vidiciatico Unit (SVU), in the Northern Apennines, is a tectonic mélange interpreted as the frontal part of the Miocene subduction plate interface between Adria and Europe (Vannucchi et al., 2008). It represents an exceptionally preserved fossil analogue of active megathrusts, allowing to investigate the mechanisms acting during the subduction process at low temperatures (T We characterized one exposure of the boundary between the foredeep turbidites on top of the underthrusting plate and the base of the SVU mélange through detailed structural analysis at the outcrop scale and systematic microstructural observation under optical and scanning electrone microscope (SEM).

The contact is lined by a less than 2 m thick fault zone, composed of multiple elongated domains juxtaposed along calcite shear veins. In the lowermost domain above the lithological contact, rocks are strongly foliated subparallel to the fault and show local evidence for "soft-sediment" deformation and stress driven dissolution of most primitive extensional veins. The overlying gray marls are cut by antithetic normal calcite shear veins and characterized by brittle boudinage parallel to the shear zone, while foliation planes, at a higher angle to the shear zone, are somewhere exploited by extensional veins. A sharp shear zone, composed of polydeformed calcite shear veins and embedded within the marls, crosscuts all other structures.

The data suggest that the studied fault rocks are the product of different deformation styles acquired from seafloor to ~4 km depth. We identified relict structures of bulk deformation of poorly lithified sediments, with superimposed localization of strain along shear surfaces coated by veins. Extensional calcite veins with crack-and-seal texture, together with evidences of stress driven dissolution, testify fluid pressure cycles active in the last stage. Many structures, as foliation planes parallel to the shear zone, extensional veins at high angle to the fault and conjugate normal shear veins suggest that the thrust acted as a weak fault. Furthermore, the main shear plain migrated upward through time, with progressive deactivation of deeper shear surfaces and incorporation of slices from the SVU to the footwall.

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Areal distribution of ground effects induced by the 2016 Mw 7.8 Pedernales Earthquake (Ecuador)

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Keywords: Earthquake hazard, earthquake environmental effects, ESI 2007 intensity scale, Ecuador.

A Mw 7.8 subduction earthquake (source IGEPN - www.igepn.edu.ec) hit the whole Manabí province and the southern part of the Esmeraldas coastal region (Ecuador, South America) on April 16, 2016 at 18h58 PM local time (nucleation depth 20 km). The epicentral area includes the town of Pedernales and its surrounding communities of Coaque, Jama, and Canoa. The coseismic ground effects were described on the field and the local earthquake intensity was evaluated using the ESI-2007 scale (Environmental Seismic Intensity Scale, Michetti et., 2007). On the epicentral area cobbles accommodated as folds, transverse cracks on highways (up to 16 cm wide in concrete road, up to 35 cm wide in asphalt road and up to 100 cm wide on loose alluvial deposit) were observed. A maximum intensity value of IX ESI2007 has been assigned to this area. On Briceno, San Vicente, San Isidro, Chone, Manta, Tosagua, Rocafuerte, Muisne, and Chamanga sites; the earthquake motion caused landslides and rock falls reaching volumes up to 8.000 - 10.000m^3 as well as liquefaction processes and water upsurges (sand boils up to 55 – 80 cm in diameters). Lateral spreading and settlement processes with fissures(ca. 25 cm wide) parallel to beachfront areas caused houses to collapse. Furthermore sinkholes up to 2.5 m in diameters were observed. Surface faulting on the San Isidro road (lateral offset of 35 cm), longitudinal and transverse cracks in asphalt roads (up to 15 cm wide), on alluvial soils (20 cm wide) and on sandy beach supratidal zone (25 cm wide) were also detected. Considering these coseismic effects, a value of VIII ESI2007 has been assigned for these areas. The generation of small rock falls and soil landslides (volume less than 250 m^3), longitudinal cracks in asphalt road (up 2 cm wide), very small pressure undulations of cobbles accommodated as folds and weak lateral spreading processes allowed to assign a VII intensity value of the ESI scale at the surrounding area of Bahia de Caraquez, Manta, Portoviejo, and Chone. The lower values intensities (VI ESI2007) were assigned to Cube, Tacusa, Colope, southern part of the Esmeraldas province. On May 18, on the same seismotectonic structure area of main shock, two Mw 6.8 (02.57 AM, local time) and Mw 6.9 (11.46 AM, local time) earthquake aftershocks (focal depth 15 km) triggered further ground damages such as: open ground cracks, sand boils, and small landslides in the, Pedernales, Muisne and Mompiche sites. The application of the ESI2007 Scale allowed consider all the local ground effects linked with the Mw 7.8 earthquake occurred in Ecuador. All the coseismic environmental data evaluated here using this scale is comparable with other earthquake intensity data obtained using the European macroseismic scale (EMS98).

Michetti A.M., Esposito E., Guerrieri L., Porfido S., Serva L., Tatevossian R., Vittori E., Audemard F., Azuma T., Clague J., Comerci V, Gürpinar A., Mc Calpin J., Mohammadioun B., Morner N.A., Ota Y. & Roghozin E. (2007). Intensity Scale ESI 2007. La Scala di Intensità ESI 2007, ed. L. Guerrieri e E. Vittori (Memorie Descrittive della Carta Geologica d'Italia, vol.74, Servizio Geologico d'Italia – Dipartimento Difesa del Suolo, APAT), Roma. http://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/memorie-descrittive-della-carta-geologica-ditalia/memdes_97.pdf

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Laboratory insights for the spectrum of Earthquake failure modes

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Keywords: Earthquakes, friction, precursors.

Seismic and geodetic observations show that fault slip occurs via a spectrum of behaviors that range from seismic (fast dynamic) to slow (quasi-dynamic) and aseismic (creep). These phenomena have been observed in a variety of active tectonic environments worldwide, however the processes that control fast or slow fault-slip speed are still poorly understood.

Here we report on laboratory experiments conducted on simulated quartz fault gouge in the double direct shear configuration where: a) we varied the loading system stiffness and used a range of normal stresses to produce the full spectrum of stick-slip behaviors; 2) we used measurements of P-wave velocity linked with mechanical data to illuminate the physical mechanisms that dictate the transition from slow to fast slick-slip; 3) we developed SEM and TEM analyses to characterize the microstructures and deformation mechanisms associated to different slip behaviour (fast dynamic, quasi-dynamic, creep).

We find systematic variations of fault zone elastic properties during the seismic cycle for the complete range of stick-slip rates indicating that slow and fast earthquakes share key mechanical features controlled by frictional properties and elastic conditions. Grain-size reduction and slip localization along micron thick shear planes is a prerequisite to generate both slow and seismic slip: plastic deformation with the development of nanometric sub-grains and local amorphization of the fault rocks is observed only during fast stick-slip.

Accelerated fault creep causes reduction of seismic velocity and elastic moduli during the preparatory phase preceding both slow and fast failure suggesting that real time monitoring of active faults may be a promising avenue to detect earthquake precursors.

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Speleotectonic evidence for a strong Holocene earthquake in the outer Central Apennines (Maiella, Italy)

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Keywords: Active Tectonics, Paleoseismology, Speleoseismology, Central Apennines.

In highly seismic active regions characterized by karst environments, speleoseismology may represents a potential tool to better constrain the occurrence and the age of late Quaternary earthquakes, as well as their seismogenic sources, kinematics and related hazard. We performed a speleotectonic study in the easternmost sector of the Central Apennine chain, an area representing the boundary between the active extensional domain, to the west, and the compressional one, to the east. The Cavallone Cave is located within the Maiella Massif, the outermost outcropping carbonate anticline of the Central Apennines, where the occurrence of "silent normal faults", to the west, and blind thrust, to the east, raises critical questions about the identification of the true seismogenic structures of this area. The most hazardous adjacent seismogenic structures are the Sulmona and the Palena-western Porrara normal faults. Whereas, a lower seismicity is probably associated to the buried Apennine thrust fronts which characterize the frontal sector of the chain.

Many structures recognized in the Cavallone Cave can be resembled to "seismothems" (i.e., speleothems potentially broken, or deformed, by a seismic event), even more so radiocarbon dating and comparison with other paleoseismological and geological data collected in surrounding areas, outside the cave, provide important constraints at least for the individuation of a strong Holocene paleoearthquake. The age of a seismothem (a stalagmite broken along a sub-horizontal cut plane with the upper part lying on the floor close to their base, accompanied with a new-growing stalagmite covering the rupture surface of the stump) found in the Cavallone Cave, in fact, matches with the dating obtained from both a trench performed along the Sulmona fault (Galli et al., 2015) and the analysis of earthquake-induced secondary effects in neighboring areas (*i.e.*, Lettopalena rock avalanche; Paolucci et al., 2001).

Moreover, although controversies exist about the correlation between spleotectonic observations and quantitative modeling, the matching of these different field data suggest the reliability of speleoseismological studies in discovering past earthquakes.

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A reappraisal of geologic effects induced by February 13, 2001 El Salvador Earthquake

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Keywords: Natural Hazard, Earthquakes, El Salvador, Earthquake-induced environmental effects, ESI2007 Scale

El Salvador is comprised inside one of the most tectonically and seismically active areas of Central America. It is characterized by two main zones of intense seismic activity: a) the subduction zone of the Cocos plate beneath the Caribbean plate along the Middle American Trench, with largest earthquakes of M> 8.0, b) a shear zone associated to the Central American Volcanic Chain, induced by an oblique component of the Cocos–Caribbean collision. This zone is characterized by moderate earthquakes of magnitude below 7.0, generally of tectonic rather than volcanic origin (De Mets, 2001; Dewey et al., 2004). A strong earthquake (M7.7), located off the Salvadoran coast, occurred on January 13, 2001, producing more than 900 deaths and widespread damages, mainly due to earthquake-induced landslides (Baum et al., 2001, Jibson & Crone, 2001; Bommer et al., 2002). This destructive earthquake was followed on February 13, 2001, by another major event localized on land, 30 km southeast of San Salvador, with a moment magnitude of 6.6 and a focal depth estimated between 10 and 30 km (MARN-SNET,2001). It produced severe and localized damages to the urban areas, and more than 300 deaths. The February event triggered additional thousands of landslides, generating the two largest landslides (Rio El Desague 1.5 million m3 and Rio Jiboa 12 million m3) of the seismic sequence (Baum et al.,2001; Bommer et al., 2002). Recent studies (Canora et al., 2010; Canora et al., 2012) have associated the February 13 earthquake to the reactivation of the San Vicente segment of the El Salvador Fault Zone, an E-W oriented strike-slip fault extending for 150 km through central El Salvador (Martinez-Diaz et al., 2004). Both earthquakes triggered also a number of soil liquefactions as well as lateral spreads, along alluvial plains and coastal flats. The high number of earthquake-induced geological effects has offered a good opportunity to re-evaluate the macroseismic parameters of the February 13 earthquake, by using the newly developed Environmental Seismic Intensity Scale (ESI2007). This scale defines earthquake intensity by taking into consideration the occurrence, size and areal distribution of earthquake environmental effects (EEE), including surface faulting, tectonic uplift and subsidence, landslides, liquefaction and tsunami (Michetti et al., 2007; Serva et al., 2015). According to the ESI2007 scale, the assessment of primary (tectonic) environmental effects, as well as the total area distribution of secondary EEEs, has provided a new value of epicentral intensity Io. A systematic comparison between intensities (MM and ESI scales) revealed differences ranging from one to two degrees, accounting for substantial differences in the damage potential. Hence, the recognition of the role in the amount and distribution of seismic damage that can be played by geological effects such as surface faulting, landslides, liquefaction, is crucial for a proper and comprehensive seismic hazard assessment.

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Primary surface faulting across the Roman Theatre at Berniki, Sea of Galilee: new archaeoseismic and structural data

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Keywords: active tectonics, archaeoseismology, Dead Sea Transform.

The Dead Sea Transform (DST) is a continental transform representing the boundary between Arabia and Sinai plates and accommodating a long-term slip rate of about 4-5 mm/a (e.g. Garfunkel et al., 2014). The DST shows the alternation of millennial periods of quiescence and seismic clusters, i.e., sequence of surface-rupturing earthquakes triggering each other in a short time laps. Seismic gaps suggest that presently several fault segments, including the Jordan Valley fault, are locked and strain is accumulating (Hamiel et al., 2016).

We focus our efforts at the N tip of the Jordan Valley, at the Sea of Galilee (SOG) area, which is a subsiding basin bounded to the E by a left-lateral fault and to the W by the Tiberias normal fault, splaying at surface into several fault strands. In particular, we investigate the seismicity and paleoseismicity of the 8th century AD, when strong shocks clustered in time and space along this sector of the DST. Disagreement still persists on the number of events, association with seismogenic sources and location of surface ruptures. This is in part due to the amalgamation of historical chronicles, resulting in the unreliable image of damaging produced by a single "giant" earthquake referred to as the "749 AD event" (Karcz, 2004; Ambraseys, 2005).

Our investigation includes (Ferrario et al., 2015): i) re-interpretation of historical chronicles and available data; ii) analysis of a 0.5-m-resolution airborne Lidar of the entire SOG shores; iii) high-resolution seismic reflection profiles; iv) archaeoseismic and mesostructural surveys at two Roman sites in Tiberias, Berniki Theatre and the Southern City Gate (v) paleoseismological analysis.

Preliminary results clearly map the strand of an active fault crossing the theatre, where a 60-cm vertical offset has been measured and dated by means of archaeological stratigraphy. A terrestrial Lidar survey, which is now in progress, will allow to measure with cm-accuracy the vertical and lateral components of coseismic displacement. We interpret the damage as primary surface faulting of one of the 8th century mainshocks. This interpretation is shading light on the "749 AD event" and contributing to the identification of the main faults which were activated during this event.

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Active tectonic evaluation in the Corace Basin (Central Calabria, Italy): insights from geomorphologic indices

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Keywords: active tectonic, geomorphologic index, Central Calabria.

In this paper preliminary results of the PhD project are presented. By means of geomorphic indices it is possible detecting landform responses to tectonics and therefore it have been broadly used to investigate tectonic geomorphology (El Hamndouni, 2008). On this purpose, some geomorphic indexes were calculated in the area of Corace Basin catchment and seven sub-basins in Central Calabria. Some geomorphic indexes of active tectonics known to be useful in active tectonic studies were selected including: Stream length-gradient index, drainage basin Asymmetry, Hypsometric integral, Ratio valley-floor weight to valley height, Index of drainage basin shape and Index of mountain front sinuosity (Smf). A high value of SL index near the Gimigliano municipality, expressed lithological changes in metabasites, serpentinites, and phyllites of the Liguride Complex tectonically overthrusted by metamorphic and crystalline rocks of the Calabrian Complex, such as orto- and para-gneisses. The outcropping rocks show a resistant behaviour, even if weathering throughout schistosity and jointing leads to the formation of granular layers that turn out to be mecanically soft and highly erodible (Tansi et al. 2007). The Af index was computed for 7 selected sub-basins of third drainage network order. Higher values of Af index in the NE and NW basins of the Corace river basin correlate to tectonic activity and lithological control. The computed Hi values of the sub-basins range from 0.24 to 0.51. Specifically those sub-basins in the southeasten part of the basin show low Hi values. Nevertheless sub-basins with structural control show concave-convex hypsometric curves with anomalies and high integral values. The Vf index is a measure of incision and not uplift; but in an equilibrium state, incision and uplift are nearly matched. For each of the selected basin, the required valley width and height data were obtained along valley cross-sections perpendicular to the drainage basin axis to calculate the Vf. The obtained values were classified into three categories: *2.5.* Relatively young drainage basins in active tectonic areas tend to be elongated in shape normal to the mountain topographic slope. In the study area, northern sub-basins show moderate to high Bs values which indicate its elongated shape. On the contrary, sub-basins in the southwest part show low Bs values. Values of Smf were readily calculated from topographic maps or aerial photography. However, the value obtained depends upon the scale.

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Tephrochronology: a continuously enhancing investigation tool of the active tectonic in Peninsular Italy

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Keywords: Quaternary and active tectonics, tephrochronology, central-southern Italy.

Analogously to any other time-dependent geological process or phenomenon, reconstructing and understanding the spatial-temporal variability of Quaternary and active tectonics is mostly dependent on high-quality and high-resolution chronological constraints. In this framework, the study of distal volcanic ash layers or tephra, ejected into atmosphere during large explosive eruptions and simultaneously deposited in different stratigraphic successions, has gained an increasing relevance to providing the critically needed time stamps. The recurrent and long-lasting explosive activity from the Quaternary peri-Tyrrhenian volcanoes and Italian volcanic arcs makes the Apennine chain a key area for the development and the application of the tephrostratigraphic method for a number of scientific issue, including Quaternary tectonics. During last decade in particular, the tephrochronology of the central Mediterranean area undergone a significant development which enhanced significantly its suitability and reliability making it an indispensable and powerful tool of investigation. After a brief presentation of the broad principles, state of art, current limitations and advantages of the tephrochronological method, some representative study cases from the Central and Southern Apennine will be illustrated.

3-D structural model of the active fault zones in the Salento Peninsula offshore (Ionian Sea, Italy)

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Keywords:3-D geological modeling, offshore active faulting, seismicity.

Active faulting in submarine environment is a geologic hazard with a causative relation to earthquakes and associated strong ground motion, tectonic deformation, landslides and rockfalls, and tsunamis. The natural hazards that are secondary with respect to earthquakes may considerably increase the damage and the casualties and increase the risk associated with the seismic impact.

The study area corresponds to Salento Peninsula offshore (Ionian Sea, Italy) considered the stable foreland of both the Southern Apennines to the west and the Hellenic arc to the east (Ricchetti et al., 1988), although it is characterized by several low energy and a few high energy earthquakes over the last centuries. The strongest historical earthquake in the last 1000 years occurred on February 20, 1743 (Ionian Sea, Imax= IX MCS; Rovida et al., 2011) and its maximum intensity has been recently re-evaluated (Imax= X MCS; Nappi et al., 2015); this event triggered a tsunami, that accumulated boulders till to 70 tons along the coastline (Mastronuzzi et al., 2007). The subsurface data, used in this work, consist of multichannel reflection profiles calibrated by well logs. Faults were interpreted on seismic reflection profiles, mapped in a GIS environment, and displayed as lines on structure contour maps and isochron maps. 2-D and 3-D modeling of geological surfaces were performed using Kingdom® software (copyright IHS Inc.). The development of dedicated software has opened a new frontier in Earth Sciences, leading to a more accurate spatial analysis of geological structure and to 3D geospatial models. The effects of faulting on the seafloor and their probable association with historical and recorded earthquakes were used to determine offshore active faulting. Hence, the active normal faults identified could pose a significant earthquake and tsunami hazards to the coasts of southern Italy (Apulia region), Albania and Greece, and should therefore be considered in any hazard evaluation.

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The San Biagio 'Salinelle' mud volcanoes (Belpasso, Sicily): a preliminary 3D subsoil model

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Keywords: Mud volcanoes, 3D model, Mt. Etna, HVSR; MASW, Sicily.

The Etna area is affected not only by volcanic activity related to the Mount Etna volcano, but also by manifestations of secondary volcanism located at some distance from the main volcano conduit and known as 'mud volcanoes'. In the lower border of the volcanic edifice occur some manifestations of mud volcanism. These phenomema are classed as pseudo-volcanic manifestations, originating from the presence of natural gases under pressure in the subsurface, but It is not fully clear if and how the activity of the mud fields would be connected with the volcanic activity of Mt. Etna.The activity of these mud volcano is characterized by a persistent emission of muddy water mixed with salts, which rises to the surface due to the gas pressure in the subsoil (Kopf 2002). These gases tend to rise through preferential migrating pathways due to the presence of permeable rocks and/or lithological discontinuities, carrying water, mud, rock fragments and hydrocarbons as they ascend. The San Biagio Salinelle are one of the three mud volcano fields located around the Paternò eruptive monogenic apparatus; this volcanic structure is one of the first sub-aerial volcanic manifestations that formed in the pre-etnean phase. Non-invasive geophysical surveys were carried out in the area of the active cone of the San Biagio Salinelle, in order to identify the shallow ascent path of the emitted products. In particular, environmental noise samplings (Nakamura Y, 1989) were taken at the nodes of a specially designed grid and subsequently the Vs values were acquired through an active seismic survey. Finally, a digital elevation model of the area (DEM), was obtained by a topographic survey, carried out with the GNSS technique (Global Navigation Satellite System), in RTK mode (Real Time Kinematic). The DEM and the topographic benchmark installed will represent the reference surface that will allow an accurate comparison with future surveys to measure all the deformations affecting the mud volcano. The data from the applied methods have been integrated and interpreted to obtain a 3D representation of the surface and a possible model showing the shallower feeding system of the investigated mud volcano. The adopted technique is fast and cost-saving, and its application to the other mud volcanoes in the area will enable their comparison and help shed some light on the factors controlling the mud volcanism in the area. Paroxystic mud eruptions can cause damage to buildings, roads, and inconvenience to the local people. The study of the San Biagio salinelle is a first step towards a more complete multidisciplinary characterization of this process with a view to mitigating risk.

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Geofluid transients as proxies of stress/strain induced permeability variations during the seismogenetic process: some examples from active tectonic and tectono-volcanic areas in southern Italy

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Keywords: Geofluid, Permeability, Seismicity, Strain, Stress, Transient.

According to the crustal transient model proposed by Bernard (2001), earthquakes and fluid flow anomalies belong to a much larger class of crustal unstable processes called "crustal transients". Transients do not occur in a fixed time sequence, implying a direct cause-effect relationship between different categories of events, nor are their magnitudes reciprocally proportional. If different transients occur in strict time relationship these could be symptoms of a wider time-space scale crustal instability.

Several studies, carried out in active tectonic and tectono-volcanic areas of southern Italy during the last decades, indicate that multi-component geofluid systems have a certain attitude to generate physico-chemical transients during different stages of the seismogenetic process.

A first class of these systems concerns the fumarolic fields. Permeability changes induced by variations of the stress field may influence the migration of water vapour from the magma source to the Earth surface: consequently, temperatures recorded in the fumarolic fields may be affected by transients, whose signs depend on the mutual orientation of the main directions of compression/dilatation and the 3D geometry of the voids network through which vapour travels up to the surface. Examples are from Mt. Vesuvius (Madonia et al., 2008), Stromboli and Vulcano islands (Madonia et al., 2013, and references therein).

Another class is related to hydrogeochemical systems composed of two sub-systems at least, characterized by a different permeability, like a mixed limestone-dolostone aquifer, where permeability is lower in the latter than in the former. Considering the Mg content as a geochemical tracer of groundwater flowing within the dolomitic portion, concentration variations of this ion could be induced by relative variations of the permeability between the limestone and dolostone, caused by a modification of the local crustal stress (pre-seismic) or by strain release (co- and post-seismic). Such a kind of process was described by Favara et al. (2007) in some springs of the Madonie mountain area in northern Sicily.

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Three-dimensional modelling of the Calabrian Subduction interface from the interpretation of seismic reflection profiles

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Keywords: Subduction, Calabrian Arc, Seismic interpretation, 3D modeling, Accretionary wedge.

The Calabrian Subduction Zone plays a key role in the evolution of the Central Mediterranean. The geometry of the subducted plate is constrained in the deeper (>40 Km) part by seismic tomography and seismicity distribution. The available reconstructions of the shallow portion of the subduction interface are based on the interpretation of single 2D seismic profiles and do not consider the three-dimensional complexity of the accretionary wedge and the interface itself. Despite the dearth of direct evidence, large past earthquakes have been sometimes associated to the shallow portion of the plate interface (e.g.: 1693 Eastern Sicily) or to the slab (e.g. 1905 Southern Calabria). Therefore, the geometrical reconstruction of this important structural system is crucial for seismic and tsunami hazard studies as shown by several recent studies.

This work presents a three-dimensional reconstruction of the Calabrian Subduction interface shallow portion based on the original interpretation of ca. 60 multichannel seismic reflection profiles (ca. 10,000 km), most of which had never been used before for this purpose. The adopted dataset is mostly composed by seismic profiles provided in the frame of the collaboration between Spectrum and INGV (CA-60), complemented by the CROP (http://www.crop.cnr.it/) and Etnaseis profiles.

The three-dimensional reconstruction highlights the detailed geometry of the subduction interface, the internal structure of the accretionary wedge and the lateral boundaries of the subduction zone.

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Paleotectonics in the Euganean hills (Venetian region). Preliminary data

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Keywords: Euganean hills, paleotectonics, landscape changing, late Alpine evolution.

The Euganean Hills provide morphological and tectonic expression of the dynamic processes that occurred in the Southern Alps upper crust during the late Alpine time. In the southernmost hills, near Arquà Petrarca (Padova) historical town, a strong brittle deformation has been observed along low angle thrusts and high angle faults in the carbonatic lithologies and in some volcanic ones. Gouges occur along the south-vergent slip planes within Scaglia Rossa Fm and in the underlying Maiolica Fm of Cretaceous age. In the Bignago area (Arquà Petrarca) gouge forms layers of whitish incohesive material, like-flour, up to15-20 m long and 5-40 cm thick, within Scaglia Rossa where deformation has reactivated stratigraphic planes and plurimetric syn-sedimentary isoclinal folds. Maiolica Fm gouge forms layer a few metres long, 10-20 cm thick associated to cataclasite. The paleontologic, mineralogical and chemical composition and geotechnical properties of these like-flour deposits found in Maiolica and Scaglia Rossa Fms have been investigated and compared with the characteristics of the surrounding cohesive rocks. The mechanical properties of these lithologies have been investigated in the mechanic laboratory to verify their behavior when submitted to stress.These incohesive layers have been interpreted as paleoseismic indicators. The geological process responsible for the observed paleo-seismic structures could be viewed in the light of the contiguous Schio-Vicenza fault tectonics or other processes post-dating the local magmatic events.

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Changing landscape in the Sarca Valley (Trentino) during Quaternary. Climate or earthquakes?

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Keywords: rock avalanches, landscape changing, historical remnants.

Rock avalanches modify the human settlement in the mountains, as suggested by the "Marocche di Dro"deposits in the lower Sarca valley, north of Lake Garda. The rock avalanche deposits (>1000x10^6 m^3 volume, 13 km^2 area) occur between the Sarche and Dro villages. The rock avalanches originated from Mt. Casale - Mt. Brento range in different times, thousands of years after the end of the glaciations. At beginning of the last century Trener discovered some roof tile fragments during the excavation of galleries near Cavedine lake suggesting a late Roman age for the rock avalanche deposit, and named it Kas. Bassetti (1997) founded Bronze age remnants at the top of the Sant'Abbondio toma near Dro and interpreted them as successive to the older rock avalanche forming the toma. Remains of Bronze ages near Cavedine testify the presence of people living in the area at pre-Roman time. Since 200 BD the lower Sarca valley belonged to the Roman X Regio and the villages (vici) were "adtributa" of Brixia. The name Kas assigned by Trener to the upper rock avalanche deposit can derive from the latin Kasae which record an agrarian activity and presence of rustica villae ("Kasae") at the bottom of the valley. It seems unusual that no city and no roads were present at the bottom, even if the valley was lovely exposed southwards, north of Lake Garda. This suggests the valley may have been continuously swampy, leaving a lake and lacustrine areas. Kas rock avalanche followed another rock avalanche fallen from Mt. Casale in the pre-historic time (Trener, 1924). Analysis of seismic catalogues indicate two strong earthquakes which struck the lower Sarca valley around 1000 AD, one dated on 1046 AD (IX MCS), the second known as "Verona" earthquake, on 1117 AD (IX MCS; Guidoboni et al., 2007). The former was at about 20 km of epicentral distance from the Marocche di Dro, the latter at about 70 km of epicentral distance. However, we cannot exclude the influence of climatic changes for the pre-historic events, mostly if related to the humid and cooler conditions of middle Holocene (Bassetti et al., 2013).

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First results of an INGV project for the integrated analysis of the active tectonics in SW Sicily

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Keywords: Sicily, Belice, Selinunte, geodesy, geochemistry, seismic profiles, geomorpholgy, archeo-seismology.

We present the first results of a project financed by the "Struttura Terremoti" of INGV to study the potential sources of earthquakes in south-western Sicily, including the area hit by the 1968 Belice earthquake sequence and the archaeological area of Selinunte, affected by two earthquakes in historical times. We adopt in this project a multi-disciplinary approach with the goal of addressing the following points: 1) define the active tectonic framework of south-western Sicily, 2) investigate and characterize on-shore and off-shore faults, potential sources of damaging earthquakes, and 3) evaluate the current deformation rates. To do this, we collected a new set of geodetic (GPS and InSAR) and geochemical data, and performed geological and geomorphological surveys on-land in the area between Mazara, Castelvetrano and Selinunte. We also acquired high-resolution Sparker seismic profiles off-shore Sciacca. Geological and geomorphological surveys have been focused around the ~10 km long Castelvetrano-Campobello di Mazara (CCM) lineament, where previous research (Barreca et al., 2014) showed geodetic and geoarchaeological evidence of recent deformation. In particular, a detailed survey of Quaternary coastal forms and deposits was performed, in order to reconstruct the sequence of uplifted paleoshorelines and to search for differential motions between adjacent coastal sectors spanning the CCM. Preliminary observations indicate that the footwall of the CCM hosts a larger number, and a more elevated position of paleo-shorelines suggestive of syntectonic uplift (Ferranti et al., this meeting). A grid of about 200 km of high-resolution reflection seismic profiles was recorded along the continental shelf in the offshore of Sciacca. Profiles are mostly oriented in the WNW–ESE direction, with tie lines acquired in ENE–WSW direction. The acoustic source used during seismic prospecting was a 1 kJ Sparker power supply with a multi-tips Sparker array. Preliminary seismic data interpretation indicates that a number of high-angle, NNE-SSW-trending, left-lateral strike slip faults are present offshore the town of Sciacca. The offset of the sea floor suggests that the fault movement is still active. Expulsions of fluids along faults have also been observed along the continental shelf where mount-shaped, cold-seep communities formed. Under the hypothesis that earthquakes related to the Castelvetrano-Campobello di Mazara lineament could have induced the destruction of the ancient city of Selinunte, a re-analysis of the archaeoseismological data on the seismic collapse of Selinunte temples allowed us to constrain the latest seismic event or seismic sequence between the 4th and the 6th century A.D. This event caused oriented collapse in most of the Selinunte temples (e.g. Temple C, D and E), whereas Temple G collapsed inwards upon itself. The different dynamic of collapse in the temple G is matter of debate among scholars and two different hypothesis have been reported so far. Some archaeologists assumed that the temple G was hypaethral, or unroofed with an open central nave and cella, whereas others that the temple was never completed. As regards the geochemistry, the results of measurements of soil CO_2 flux carried out in the north-eastern area of Belice Valley highlight the presence of sites with high degassing level (up to 350 g m-2 d-1) with a CO2 supply of crustal origin. The sites with crustal contribution are mainly aligned along NE-SW direction. The tectonic control on the geochemical characterization and flow path of groundwater is particularly evident in the Santa Ninfa gypsum karst structure, located within the area hit by the 1968 seismic sequence, and close to the epicentres of the most energetic seismic events (M>3.0) occurred in the Belice area during the last 30 years. We also collected GPS data from permanent and episodically surveyed station in SW Sicily with a twofold aim: 1) to retrieve new insights about the geodynamics of this sector of Sicily and 2) to verify the active deformation of the creeping segment already identified by Barreca et al. (2014) between Campobello and Castelvetrano. We re-surveyed the IGM (Istituto Geografico Militare) benchmarks of this area and a new dataset of benchmarks already measured in 2007 by the University of Palermo for cartographic applications. Finally, the SENTINEL 1A TOPSAR Advanced DinSAR analysis covering the 2014-2016 time spanning, confirms the presence of a lineament running NNE-SSW between Campobello and Castelvetrano, showing meaningful LOS displacements.

Barreca G., Bruno V., Cocorullo C., Cultrera F., Ferranti L., Guglielmino F., Guzzetta L., Mattia M., Monaco C. & Pepe F. 2014. Geodetic and geological evidence of active tectonics in south-western Sicily (Italy). Journal of Geodynamics, 82, 138-149

Ferranti L., Burrato P., Forlano S., Di Donato V., Amore O.F. (this volume) - Mid-late Quaternary uplift of the coastal sector between Mazara and Selinunte (SW Sicily): hints on active tectonic structures.

The multi-scale cross-coupling between transient deformation and earthquakes

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Keywords: microseismicity, crustal deformation, slow slip event, fluid pressure, earthquake nucleation.

In the last two decades, thanks to a steadily increasing number, density, and quality of monitoring seismological and geodetic arrays, a considerable amount of refined observations has revealed a large variety of slow, transient instabilities in active fault systems, in the interseismic period between large earthquakes. These transient had led Ide et al. (2007) to propose a generic class of slow earthquakes, distinct from earthquake ruptures, spanning a large range of time scales - from fraction of seconds to years- and moment (or strain energy) - from M=1.5 to M=8. These events show a scaling relationship between time and moment very different from that of earthquakes: for a given moment, the transient process appears to be very slow. Increasing the duration and moment, one finds low frequency earthquakes, tectonic tremors, and various scales of slow slip events. The role of these transients within the seismic cycle of large earthquakes is a matter of intense research and debate, in particular for what concerns their ability to prepare or trigger their nucleation. To enlarge and enrich this view, one can consider three main categories of mechanical processes of instabilities within fault systems, instead of two: seismic ruptures, slow creep, and pore pressure migration. Direct observations of the latter are however very seldom, and pore pressure effects are usually inferred from seismic and/or creep observations. Furthermore, creep and/or pore pressure effects are thought to be cross-coupled, and at the origin of many if not most of the clustered microseismicity, in particular transient swarms. Thus, understanding the cause of space-time variations of microseismicity and its relationship with large earthquakes requires to work in the more general perspective of the mechanical cross-coupling between seismic ruptures, creep events, and pore pressure migration. In the absence of direct strain measurement by geodetic instruments, these forcing slow transient have to be inferred from the characteristics of the microseismicity, which is attempted through several data processing techniques, in particular on earthquake catalogs (advanced, statistical epidemic-type models) or on seismic waveforms (advanced multiplets and repeater analysis). These approaches, developed in the context of natural fault systems, may also prove very useful for understanding induced and triggered seismicity, in particular in oil, gas, or geothermal production fields. Deciphering the cross-coupled mechanics of slow and fast (i.e. seismic) instabilities, with appropriate monitoring systems, processing tools, and numerical/theoretical models, is thus the challenge of the research on seismogenesis for the coming decades. In this talk, this global framework will be illustrated through a couple of case-studies, and recently published cases relating these transients to the occurrence of large, destructive earthquakes (Tohoku 2011, Iquique 2014) will be presented and discussed.

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Active deformation in a sector of the Sicilian-Maghrebian Chain: new insights from integrated GNSS, structural high-resolution seismic reflection and seismological data

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Keywords: Active thrusting, Sicilian-Maghrebian chain, North Sicily, GNSS velocity.

We document active deformation in a sector of the Sicilian Maghrebian Chain exposed in north Sicily and in its offshore prolongation on the basis of the integrated analysis of 1) time series of data collected by GNSS acquisition representing the change in the positions (X and Y) of permanent stations located in Palermo, Partinico, Prizzi, and Termini compared to the IGS station of Noto, 2) high-resolution (Sparker) single-channel reflection seismic data, 3) structural data, and 4) seismological data. The average values for the velocity vectors obtained for the Palermo, Partinico, Prizzi, and Termini Imerese stations are 4.55, 2.97, 2.96, and 2.15 mm/yr, respectively. The direction of the velocity vectors for all stations is oriented towards the station IGS reference of Noto. The relative displacements of the Termini Imerese, Partinico and Prizzi stations respect to Palermo station are most equal to 0.5 mm; the directions of vectors are divided between them, with a clockwise rotation. In the area cropping out in the promontory of Capo Zafferano, Pleistocene conglomerates and grainstones are affected by recent tectonic deformation. Particularly, two sets of deformation bands striking: i) from N-S to NNW-SSE and ii) NE-SW are observed at two sites near the village of Porticello. Both sets have an almost vertical dip and show mutual cross-cutting relationships which suggest that they developed contemporaneously. The N-S/NNW-SSE striking set shows a left-lateral strike slip kinematic. At place, the deformation bands affect also Upper Pleistocene (Tyrrhenian) bio-calcarenites. A number of seismic units, which are bounded by unconformities, were identified on seismic lines based on the internal configuration and seismic-stratigraphic character of reflectors (amplitude, reflection continuity, external shape, and frequency). The shallowest seismic unit is limited at the bottom by an erosional unconformity which cuts the underlying units. This unconformity formed during the sea level lowstand of the Last Glacial Maximum (LGM), aged at~20 ka. The unit of inferred late Pleistocene age appears to be folded and faulted. Faults generally have an inclination of ca. 50°, small displacements up to 10 m and are sealed by the unit of inferred post LGM age. Only a limited number of these faults were observed moving ca. 3 km offshore towards the NE. The study area has been struck in the past by several significant earthquakes of $I0 \geq 6$, and we jointly evaluated data and information available for these events with the results of analyses performed to define the spatial distribution and kinematics of the recent seismicity.

Spatial variation of the crustal stress field in the southern Calabrian Arc

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Keywords: Active tectonics, Calabrian Arc, stress field, earthquakes.

In this work we compiled a catalogue of crustal stress indicators obtained from the inversion of structural and seismological data. The main objective is to recognize and discuss the Late Quaternary-to-present tectonic stress field of the southern portion of the Calabrian Arc. The structural dataset contains published and unpublished information relative to Quaternary outcrop- and regional-scale structural features. We measured about 1400 meso-scale structural features at 39 different sites. The seismological dataset consists of 441 focal solutions belonging to 380 earthquakes, all coming from published papers and relative to crustal events (depth < 35 km); the information provided by different authors has been homogenized by calculating the direction of T, P and B axes. The collected stress indicators have different reliability and a we thus attributed a quantitative ranking before performing a meaningful statistical analysis. Our ranking system considers both the reliability of the kinematic information and the volume of rock associated to each stress indicator. The catalogue is not evenly distributed on the study area, however it is possible to perform their interpolation to obtain a regularly distributed grid. Data have been interpolated separately for each horizontal principal stress in order to reconstruct their trajectories throughout the study area. We also separated the crustal events and the analyses in shallow (<15 km) and deep ones (15-35 km). The three maps for each crustal layer allows to emphasize important lateral variations within the investigated area. Moreover, the joint interpretation of the maps allows to distinguish different tectonic regimes, their orientations and their distribution. In particular, we recognize a purely extensional regime with a (W)NW-(E)SE trending sigma3 in NE Sicily and southern Calabria, a compresional one (NW-SE sigma1) west of the Nebrodi Mountains, transcurrency in the south Tyrrhenian Sea (N-S sigma1 and E-W sigma3) and a radial extensional regime in an E-W trending sector including Capo Vaticano promontory and the southernmost Calabria coastal area. The results obtained in this study for the southern Calabrian Arc could be compared with independent geodetic or tomographic information.

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Seismicity in the Mercure basin (Calabria-Lucania border, southern Italy) following the 2010-2013 Pollino seismic sequence: existence of both shallow extensional and deep strike-slip kinematics?

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Keywords: Recent seismicity, Seismotectonics, Mercure Basin, calabro-lucano border.

Between 2010-2013, a seismic crisis (the Pollino sequence) affected the area southeast of the Mercure basin, with Ml≤5.0 extensional earthquakes distributed between 5-10 km depth (Totaro et al., 2015). The faults activated at depth during the sequence are thought to be secondary structures (Totaro et al., 2015) compared to WNW-ESE striking faults that bound to the north the Mercure basin and are considered to be the main seismogenic sources of the area (Brozzetti et al., 2009). After the Ml=5.0 event occurred on October 25, 2012, the seismicity in the epicentral area abruptly decreased and the sequence could be considered ended in spring 2013.

In order to assess the latest background seismicity of the Mercure basin and surroundings, we analyzed the seismicity between June 2013 – December 2015, immediately following the significant slowdown of the Pollino sequence. We utilized data recorded by the seismic stations belonging to the Italian National Seismic Network of the INGV. In order to obtain reliable hypocentral events distributions and fault plane solutions, we collected the waveforms of the events occurred in the area between Latitude 39.300 – 40.140 and Longitude 15.800 – 16.200 to perform a re-picking of P- and S-phases and to obtain a P-wave dataset polarity. Overall, ~250 events with 1.0≤Ml≤3.0 were re-located and ~25 well constrained focal mechanisms were computed.

This analysis has revealed a hitherto partly unexpected distribution and kinematics style of seismic activity. The hypocentral distributions show that about 85% of the events are confined between ~5-12 km depth, whereas the remaining events have depth between 16 and 20 km. Focal mechanisms of the 5-12 km deep events show extensional kinematics. For each of the above mechanisms we performed a detailed surface projection of nodal planes from the focal depth to search for possible relation with the mapped normal faults (Brozzetti et al., 2009; Totaro et al., 2015). Although the dataset is limited, we found that several events are consistent with activation of the deep (5-12 km) part of the WNW-ESE striking Castelluccio and Piana Perretti faults, the latter considered the seismogenic structure of the Mw=5.6 1998 earthquake (Brozzetti et al., 2009).

Relatively to the second, more limited group of events distributed between 16-20 km depth, 9 of them (Ml<2.5), all with focal depth around 20 km, occurred in few hours on August 28, 2013. The fault plane solutions of this swarm are characterized by strike-slip kinematics with ~E-W and N-S nodal planes. This somewhat surprising result is consistent with a penetration of the deep strike-slip regime (Ferranti et al., 2014), which characterize the eastern part of southern Italy, also beneath its western part.

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Looking for active and capable faults in Friuli: a multidisciplinary approach to study the Maniago thrust (western Carnic Prealps, NE Italy)

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Keywords: active tectonics, capable faults, eastern Southern Alps, Friuli.

In the framework of the agreement between the Friuli Venezia Giulia Region (Geological Service), ISPRA and University of Udine, in order to improve knowledge about the active and capable faults in the Friuli Venezia Giulia Region and update the ITaly HAzard from CApable faults (ITHACA) database, new geological, morphotectonic, geophysical and paleoseismological studies were carried out on the Maniago thrust (western Carnic Prealps, Friuli) near Meduno (PN). The Maniago thrust belongs to the Quaternary front of the eastern Southern Alps (ESA), a polyphase fold and thrust belt in evolution from the Middle Miocene to the Present. The external front of the ESA is arranged in a set of WSW-ENE trending, SSE-verging, middle angle, mostly blind thrusts involving both the uppermost Pleistocene (i.e. LGM) and Holocene sediments cropping out in the pre-alpine area and in the Friuli piedmont Plain. Morphotectonic investigations identified surficial traces of the recent fault activity, generally represented by drainage anomalies and gentle scarps connecting uplifted and back-tilted Quaternary paleo-landscapes with the plain. Tectonic activity is also testified by the historical and instrumental seismicity that make the Friuli region one of the most seismic region in N-Italy. In particular the study area is located at the lower reach of the Meduna valley, where the incision of the Meduna River crosses the Miocene succession and starts to cut the Pliocene-Holocene alluvial deposits of the piedmont plain. The study shows that the valley configuration has been shaped during the Pliocene-Quaternary with long lasting steady intervals, spaced out by periodic tectonic pulses linked to the activity of the thrust front of the ESA. The most recent pulse related to the Maniago thrust shows an Upper Pleistocene – Holocene slip-rate of about 0.5-0.6 mm/a (Monegato and Poli, 2015). During the last pulse the activity of the Maniago thrust gave rise to a tectonic scarp (about 800 m long and 1-4 m high) shaped in the LGM Rivalunga terrace near Meduno. Integrated geophysical investigations (electrical resistivity tomography, seismic refraction and reflection, Ground Penetrating Radar (GPR), passive seismic (HVSR, ReMi) and MASW) were performed across this morphological feature, confirming its tectonic origin. The digging out of two paleoseismological trenches showed that the Maniago thrust is not only an active fault but also a capable one. Moreover the very recent age of the deformed stratigraphic units (1460 AD), compared with the DBMI-11 Catalogue, allowed to consider the 1776.07.10 earthquake (Imax=8-9), as the last seismic event linked to the Maniago thrust tectonic activity.

Monegato G. & Poli M.E. 2015. Tectonic and climatic inferences from the terrace staircase in the Meduna valley, eastern Southern Alps, NE Italy. Quaternary Research, 83, 229–242.

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Seismic moment release and cumulative moment tensor maps of the Italian peninsula

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Keywords: Seismic moment tensors, tectonic styles and faults, Italy.

A collection of all seismic moment tensors available for Italy for earthquakes with a M greater or equal to 4.0 for the last 50 years has been gathered. It contains data from different catalogs or datasets, mainly populated by moment tensors computed through inversion of seismic waves (e.g. CMT, RCMT, GFZ and ETHZ MT and so on). However, for great earthquakes of the past, i.e. the 1962 Irpinia or the 1968 Belice earthquakes, we used data obtained with other methods, but considered the best available information for that period.

We used all these data to find the fault mechanism that we can consider as the typical one for a particular region or, on a regular grid, for all most seismic areas of the peninsula and regions around. To identify and draw the most seismic regions of the peninsula, we used data from historical and recent instrumental seismicity (CPTI11, Rovida et al., 2011, http://emidius.mi.ingv.it/CPTI and INGV bulletins, http://http://iside.rm.ingv.it/) summed on a regular grid, obtaining seismic moment release maps.

Overlapping cumulative moment tensors to seismic moment release maps we identify regions clearly characterized by different tectonicsThe extension is the principal type of deformation along most of the Apennines, somewhere interrupted by strike-slip mechanism. Compressive deformation appears in the eastern Alps, in the outer part of the northernmost part of the Apennines, in several parts of the Adriatic Sea and in the off shore of Northern Sicily. We consider this tectonic style mapping helpful to draw a zonation that can be used for seismic hazard evaluation.

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Can grain size sensitive creep lubricate faults during earthquake propagation?

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Keywords: Fault Lubrication, Earthquake Propagation, Carbonates, Grain Boundary Sliding, Creep.

In the shallow portion of crustal fault zones, fracturing and cataclasis are thought to be the dominant processes during earthquake propagation. In the lower crust/upper mantle, viscous flow is inferred to facilitate aseismic creep along shear zones. Recent studies show that cohesive slip zones (SZs), in natural and experimental carbonate seismic faults, are made of nanograin aggregates with a polygonal texture, a microstructure consistent with deformation by grain boundary sliding (GBS) mechanisms.

Friction experiments performed on calcite fine-grained gouges, at speed v >10 cm/s and room temperature and humidity, show a four stage-evolution of the fault strength with increasing displacement: SI) attainment of initial Byerlee's values, f = 0.6-07; SII) increase up to peak values, f = 0.8-0.9; SIII) sudden decrease to low steady-state values, f = 0.15-0.3; and SIV) sudden increase to final value, f < 0.6, during sample deceleration.

Microstructural analysis on samples recovered at the end of each displacement-controlled experiment (Stages I–IV) shows particle comminution up to nanometric scale (<< 1μm), even after small amounts of slip, and an evolution of the architecture of the SZ material, which is: SI) poorly consolidated and made of fine-grained (1 < D < 5 μm), angular clasts formed by brittle fracturing and cataclasis; SII) cohesive, organized into regularly spaced Riedel shears and made of larger clasts of calcite ($D \approx 1$ μm), exhibiting a high density of free dislocations and hosting subgrains (D < 200 nm), dispersed within calcite nanograins (D<200 nm); SIII-SIV) strain localisation into a thin slip zone (< 200μm) made by specular layers of sintered nanograin aggregates exhibiting polygonal grain boundaries and 120° triple junctions between equiaxial grains (D ≈ 600-700 μm), sandwiching a porous layer of finer particles. The grains display no preferred elongation, no crystal preferred orientation and low free dislocation densities, possibly due to high temperature (> 800 °C) GBS creep deformation.

Our microstructural observations suggest that GBS mechanisms can operate in geological materials deformed at high strain rates along frictionally heated seismogenic slip surfaces. The observed microstructures in experimental slip zones are strikingly similar to those predicted by theoretical studies, and to those observed during experiments on metals and fine-grained carbonates deformed at T > 900 °C, where superplastic behaviour due to GBS has been inferred. A regime of frictionally-induced GBS could thus account for the dynamic weakening of carbonate faults during earthquake propagation in nature.

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Activity migrates between parallel sets of active normal faults on millennial timescales: implications for the mechanics of continental deformation and seismic hazard.

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Keywords: Slip-rates, normal faults, 36Cl dating, Italy.

Normal, thrust and strike-slip fault systems commonly contain parallel sets of active faults. However, it has been unclear how these parallel faults interact over multiple seismic cycles to accommodate the regional strain. Geodetic measurements and the locations of instrumental seismicity can be used to infer where recent deformation has localised. However, we ask how typical these decadal measurements of strain are for longer time periods that contain multiple large earthquakes on every fault within the system of parallel faults. Such time periods must be many thousands of years if fault-specific earthquake recurrence intervals are hundred to thousands of years, as indicated by palaeoseismology. We present ^{36}Cl cosmogenic data that constrain how fault slip migrates through time between parallel sets of faults in central Italy. ^{36}Cl cosmogenic dating can be used to date the time of exhumation of rock surfaces at the Earth's surface. It follows that ^{36}Cl can be used to record the rates of slip across normal faults because faults planes are progressively exhumed to the Earth's surface by repeated earthquakes. Our ^{36}Cl results, supported by detailed field mapping of the normal faults, show that although activity in the form of large earthquakes since 1349 A.D. and interseismic strain in the last few decades have mainly been localised on faults occupying the NE flank of the topography of the Apennines, slip on faults was localised on the SW flank between ~2000-660 years BP, and on the NE flank from ~5000-2000 years BP. The time period of ~2000-660 years BP is coincident with Intensity VII and VIII damage in Rome recorded in the disrupted architecture of the Colosseum and the Roman Forum. The SW flank of the Apennines has experienced minimal seismicity and geodetic strain in the last few decades. These results show that although geodetic measurements and the locations of instrumental seismicity can be used to infer where recent deformation has localised, they do not constrain the location of strain over millennial time scales and strain can migrate back and forth across the strike of parallel sets of faults over multiple seismic cycles. It is implied that records of strain accumulation over many thousands of years are needed to allow studies of the mechanics of deforming regions and the geography of seismic hazard.

Kinematics, seismotectonics and seismic potential of the Eastern Southern Alps from GPS and seismic deformation data

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Keywords: Eastern Alps, active tectonics, kinematics, GPS, earthquake cycle, seismic potential.

We discuss the kinematics and seismotectonics of the Eastern Alps of Italy, Austria, Slovenia and Croatia, as obtained from the analysis of geodetic and seismological data. The study area marks the boundary between the Adriatic and the Eurasian plates, through a wide zone of deformation including a variety of tectonic styles within a complex network of crustal and lithospheric faults, inherited by the geodynamic evolution of the Alpine-Dinaric-Carpathian system. We use a dense GPS velocity field, a focal mechanisms catalogue and a seismic catalogue, with uniformly re-calibrated Mw (from AD 1005), to estimate the tectonic deformation rates (i.e., geodetic strain-rates and seismic flux) and to develop inter-seismic kinematic and coupling models, providing new insights into the active faults and seismic potential of the study area. The Eurasian-fixed GPS velocities reveal the overall kinematics, with a transition from NNW-ward to NE-ward motion trends across Slovenia and Austria, toward the E-ward motion of the Pannonian units. The geodetic deformation field and the map of the seismic flux consistently highlight two belts of higher rates running WSW-ENE along the Eastern Southern Alps (ESA) in Italy and E-W in Slovenia, where the greater part of the Adria-Eurasia convergence is accommodated. Velocities defined in local reference frames (i.e., Adria-, Alps- and Pannonian-fixed frames) highlight secondary and more localized kinematic features, revealing a complex configuration of interacting tectonic blocks. Adria-fixed velocities show geodetic shortening occurring tens of km southward of the south Alpine mountain front in the Venetian plain, in regions struck by large historical earthquakes (e.g. the 1117 Verona and the 1695 Asolo events). The Montello-Cansiglio area, in particular, displays the highest deformation rates of the study area but low values of the seismic flux, which is higher in Friuli, Slovenia and northern Croatia. The inner sectors of the Venetian and Carnic Alps move in different directions, implying that this block, intermediate between Adria and the Eastern Alps wedge, is internally deforming, but the low rates and the number of GPS sites do not allow to significantly distinguish smaller blocks. We find that rather than the Periadriatic lineament, most of the dextral shear between the Eastern Southern Alps and the Eastern Alps blocks is accommodated along the Fella-Sava and the E-W trending Periadriatic faults in Slovenia. In northern Croatia and Slovenia we constrain the kinematics of the active structures bounding the triangular-shaped region encompassing the Sava folds, which plays a major role in accommodating the transition from Adria- to Pannonian-like motion trends. The analysis of intserseismic elastic coupling along the Eastern Southern Alps thrust front, of the seismic and geodetic moment release rates provides new insights into the seismic potential of the study region.

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Phyllosilicate occurrence along extensional faults in carbonate rocks and implications for seismic slip propagation: case studies from the central Apennines, Italy

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Keywords: Fault zone evolution, clay, seismic slip, earthquake.

The occurrence of phyllosilicate-rich layers and phyllosilicate-rich fault rocks has been documented and studied, for the first time, in five shallow (exhumed from depths < 3 km) carbonate-hosted extensional fault zones from the seismically-active central Apennines, Italy. The brittle portion of this domain is dominated by a sedimentary sequence consisting of ~5-6 km thick platform carbonates deposits upward followed by ~2 km thick phyllosilicate-rich deposits (marls and siliciclastic deposits). Along sharp fault surfaces within carbonate-hosted fault zones, the phyllosilicate-rich layers are usually thin (a few centimeters to decimeters thick), but can reach also a few meters in thickness. Structural, microstructural, and mineralogical analyses show that phyllosilicates derived from the overlying marls and sandstones and were involved during tectonic deformation. During fault zone evolution, phyllosilicate-rich material percolated downward into pull-aparts (i.e., dilational jogs) generated along staircase faults. With further displacement accumulation, this clayey material was smeared and concentrated into narrow layers along the fault surfaces. The occurrence of phyllosilicates promoted frictional sliding along weak phyllosilicate bands, which is energetically favored rather then cataclasis within strong carbonate rocks. These observations implies that, even in a tectonic setting dominated by high frictional strength rocks (e.g., carbonates), localized layers enriched in weak phyllosilicates can reduce the expected fault strength during earthquake, promoting seismic slip propagation up to the Earth's surface and surface faulting. This concept can be valid in many other seismically active extensional settings where low friction and weak phyllosilicate-rich rocks overlain or are juxtaposed with high friction rocks.

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Late Quaternary contractional deformation along the southern flank of Mount Etna: new evidence from the Catania urban area

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Keywords: Mt. Etna, thrust ramp, Late Quaternary deformation, seismic hazard.

The seismic microzonation studies carried out between 2008 and 2014 in the lower eastern flank of Mt. Etna, in eastern Sicily, provided new evidence of the Late Quaternary contractional deformation affecting this sector of the volcano. The new field data, combined with the interpretation of well logs, suggest to relate the wide culmination of the sedimentary substratum, outcropping to the north of Catania, to the hangingwall of two main E-W to ENE-WSW oriented, N-dipping thrust-ramps. The two contractional features can be traced taking into account the different stratigraphy at the hangingwall and the footwall of the structures.

The southernmost thrust ramp, here named Catania-Aci Castello Thrust, extends along the northern border of the Catania urban area. The base of the stratigraphic succession exposed in the hangingwall of the structure consists of the basal Early-Middle Pleistocene marly-clay succession, with the interleaved tholeiitic submarine lavas (580-460 ka B.P.), evolving to about 50 m of marine sands. The sedimentary substratum is capped by the alkaline volcanic cover, starting from about 145 ka B.P.. Boreholes drilled in the footwall evidence the differential vertical displacement of the distinct stratigraphic horizons. The tholeiitic levels, interleaved in the sedimentary substratum, are displaced for at least 400 m; the base of the alkaline lavas, at the top of the substratum, is offset for about 190 m. The vertical displacement-rates can be thus estimated between 0.9 to 1.4 mm/a. The Holocene lava flows seem to drape undisturbed the structure. Nevertheless, the Holocene coastal wedge, drilled by boreholes in the footwall of the thrust, rests at about 2 m b.s.l., whereas relics of the Holocene abrasion surface have been uplifted at about 4 m a.s.l., in the hangingwall..

The northernmost thrust ramp, here named San Gregorio Thrust, extends from San Gregorio to Aci Trezza. The hangingwall of the structure represents a deeply eroded culmination of the sedimentary substratum, where both the sand levels and the top of the marly clays succession, hosting the tholeiitic lavas, are missing. In this area, the base of the alkaline lavas, directly covering the lower part of the marly-clay sequence, shows a vertical offset through the ramp of about 120 m. We can thus estimate a vertical displacement-rate of about 0.9 mm/a. Also in this case, the Holocene lavas seem to cover undisturbed the structure. Nevertheless, the two described contractional structures actually represent mobile belts pictured by both GPS and DInSAR data. In addition, an Holocene thrust ramp was already described in the southern suburb of the Catania Town. Further investigation along these two thrust ramps would be necessary to test their seismogenic potential and complete the assessment of the seismic hazard in this densely populated region.

Seismically induced ground effects of the December 2013 – January 2014 Matese seismic sequence (southern Apennines, Italy)

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Keywords: earthquake ground effects, surface rupture, southern Apennines.

The Matese area has recorded in historical times a number of earthquakes with magnitude around 7 and frequent moderate earthquakes (Rovida et al., 2011). Active tectonics in this area is testified by geological, geomorphological and morphometrical data (Valente et al., 2015a). From December 2013 to January 2014, the SE sector of the Matese massif has been affected by a low to moderate magnitude seismic sequence. The main event, with Mw 5.0 according to ISIDE (http://iside.rm.ingv.it) occurred on December 29th 2013 with hypocentral depth ranging from 12 km to 20 km, and was characterized by a NW-SE trending extensional focal mechanism (Ferranti et al., 2015)

The 2013-2014 seismic sequence caused ground effects in an area of about 90 km^2 (Valente et al., 2015b). Several rock falls affected the carbonate ridges in the area around the villages of San Gregorio Matese and Pietraroja. Discharge variations and an increase of turbidity in one of the major springs have been recorded. Local people also described the occurrence of a flame just a few seconds before the main shock.

A coseismic rupture in the carbonate bedrock on the SW border of a small intramontane basin located about 1.5 km SE of the Mt. Airola was reported by local people. The rupture is striking N120, NE facing, ~0.3 m high and 50 m long. The rupture affects a rectilinear scarp bounding the basin to the SW and is dissected by a hanging valley. These features suggest the occurrence of a fault bounding the Mt. Airola basin to the SW. We have carried out a geoelectrical investigation in order to reconstruct the geometry of the Mt. Airola basin, and to derive information on the features of the coseismic rupture. The results constrain the geometry of the carbonate substratum of the Mt. Airola basin and point to the occurrence of an abrupt, subvertical contact between the carbonates and the Quaternary filling of the basin. The boundary between the carbonates and the basin fill may be interpreted as a NE-dipping fault zone, within which the coseismic rupture is localized.

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Could the collapse of a massive speleothem be the record of a large paleoearthquake?

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Keywords: Speloseismology, spleothem vulnerability modelling, paleoerthquake, Cola cave, Fucino plain.

Earthquake forecast and seismic hazard models are generally based on historical and instrumental seismicity. However, in regions characterized by moderate strain rates and by strong earthquakes with recurrence longer than the time span covered by historical catalogues, different approaches are desirable to provide an independent test of seismologically-based models. We used non-conventional methods, such as the so-called "Fragile Geological Features", and in particular cave speleothems, for assessing and improving existing paleoseismological databases and seismic hazard models. In this work we present a detailed study of a massive speleothem found collapsed in the Cola Cave (Abruzzo region, Central Apennines, Italy) that could be considered the record of a large paleoearthquake. Laboratory analysis included radiometric dating of the speleothem and geothecnical measurements to characterize its mechanical properties. We performed theoretical and numerical modelling in order to estimate the values of the horizontal ground acceleration required to failure the speleothems. In particular we used a finite element method (FEM), with the SAP200 software, starting from the detailed geometry of the speleothem and its mechanical properties. We used several individual seismogenic source geometries and four different ground motion prediction equations to calculate the possible response spectra. We carried out also a seismic noise survey to understand and quantify any amplification phenomenon. The results suggest two faults located in the Fucino area as the most probable causative sources of the cave speleothem collapses, recorded ~4-5 ka ago, with an inferred Mw=6.8 ± 0.2, and values of peak ground acceleration included between 0.54*g* and 0.63*g*. Furthemore, we performed U/Th and radiocarbon dating of collapsed speleothem and of post-fall concretions. The results, compared with published paleosismological data from geological studies allowed us to detect at least three large shocks during the last 12.5 kyr. Our approach contributes to assess the existence of past earthquakes integrating the classical paleoseismological trenches techniques and can give an important contribution to improve the investigation of active tectonic processes in relation to the seismic cycle.

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Pre- and co-seismic surface deformation of graviquakes: the 1997 Colfiorito earthquake (Northern Apennines, Italy)

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Keywords: Colfiorito earthquake, normal fault earthquakes, SAR Interferometry, precursory phenomena, foresh

Normal fault-related earthquakes, or graviquakes, are dissipation of gravitational energy (Doglioni et al., 2015; Petricca et al., 2015), which cause vertical ground motion associated with damages and fatalities. The study of seismic-induced ground motions is significant for mechanical analysis of fault zones and seismic hazard assessment within seismically active extensional tectonic settings (e.g., Apennines, Turkey, Greece). In this work, Synthetic Aperture Radar Interferometry (InSAR) was applied to estimate the surface displacement field caused by the 1997 Colfiorito (central Apennines, Italy) M_w 6 extensional earthquake, which nucleated at ~7.5 km depth along the Mt. Pennino normal fault zone. Two months before the mainshock (i.e., during the pre-seismic phase) the onset of ~2 cm of ground subsidence was observed within the future epicentral area. During the month before the mainshock, subsidence continued concurrent with the onset of foreshocks and of fluid migration into the fault zone at depth (Ripepe et al., 2000). Pre-seismic subsidence was probably caused by the onset of fractures closure within the fault zone (Doglioni et al., 2014; Doglioni et al., 2015). The co-seismic phase was characterized by a maximum subsidence of ~11 cm within the epicentral area (Stramondo et al., 1999) coupled with fluid migration at depth and fluid discharge from springs (Doglioni et al., 2014; Quattrocchi et al., 2000; Miller et al., 2004). On the other hand, during the post-seismic period, were not observed significant surface deformations. The observed co-seismic subsidence and fluid discharge can be related to the gravitational fall of the hangingwall block volume, which caused fracture closure and related squeezing out of fluids. These observations are important for earthquake forecasting, as, in the future, the measurement of fluid pressure fluctuations (e.g., into deep borehole) during the pre-seismic phase could be a reliable earthquake precursor.

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High-resolution earthquake catalogs to characterize fault zone structure and its properties

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Keywords: fault zone structure, seismic vs aseismic slip behavior, high-resolution earthquake catalogs.

The characterization of fault zone structure and its time-dependent properties is essential for understanding the physical processes responsible for earthquakes and faulting. Seismology provides many of the high-resolution tools needed to peer into fault zones. In the last two decades, improvements in the acquisition, archiving and processing of large seismological data have increased the resolution by more than one order of magnitude. This allowed us to progress in the description of the fault geometry from the kilometer scale to the identification of secondary structures tens of meters long, resembling the degree of complexity observed by field geologists at the fault outcrops. Furthermore, the analysis of transient properties of the fault zone (e.g., velocity structure, Vp/Vs, *b*-value, pore fluid pressure) and of different types of seismic signals (e.g., high/low frequency earthquakes, repeating events) denotes the presence of a wide spectrum of seismic behavior (e.g., seismic vs aseismic "creeping" behavior).

Despite recent progresses, we still have much to learn about how fault zone properties such as geometry, mechanics, and pore fluid pressure combine to determine the earthquake rupture evolution and/or how the rheological properties of fault zone materials govern seismic or aseismic slip behavior.

In this talk, we attempt to answer these questions by using data from two large high-resolution earthquake catalogs recorded along active normal faults located in the Apennines: the 2009 Mw6.1 L'Aquila earthquake sequence (Central Apennines); and the long-term (2010-2014) earthquake catalogue recorded along the actively slipping low-angle (< 15°) Altotiberina normal fault and the associated complex network of synthetic and antithetic faults located in the low-angle fault hanging-wall, characterized by intense and long-lasting seismicity production (Northern Apennines).

Both catalogs, compiled by means of automatic procedures able to analyze large amount of seismic data, are characterized by a very low magnitude of completeness (around 0.5 ML) and by earthquake location uncertainties in the range of a few meters to tens of meters, i.e., lower than the spatial dimension of the source of the earthquakes.

By analyzing these two case-studies, we will give insights on the fault zone structure at depth with a resolution comparable with geological field investigations. We will explore the role of fluid pressure in earthquake generation processes by analyzing the spatiotemporal seismicity pattern and related seismicity parameters (*b*-value and Vp/Vs ratio). Finally, we will try to develop an understanding of the rheological properties of fault zone materials that govern seismic or aseismic slip behavior, by mapping the portions of the fault characterized by the presence of clusters of repeating events in relation to the spatial distribution of b-value and Vp/Vs ratio.

SESSION S2

Structural Geology all-round on the Earth and other planets: case studies, modelling and industrial applications

CONVENERS AND CHAIRPERSONS

Massimiliano Rinaldo Barchi (Università di Perugia)
Sveva Corrado (Università di Roma Tre)
Matteo Massironi (Università di Padova)
Fabrizio Storti (Università di Parma)

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Toward an update of the structural model in Italian submerged areas: contributions from the EMODnet Geology Project

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Keywords: structural model, Italian seas, EMODNet Geology Project, digital maps.

The European Marine Observation and Data Network (EMODNet) Project aims at the collection of as many existing data as possible on European Seas to be represented on digital maps at the 1:250,000 scale, accessible via web through a dedicated portal. It is articulated into different *Lots* concerning Bathymetry, Geology, Biology, Chemistry, Physics, Physical Habitats, Human activities.

The *Geology Lot* is realized by a Consortium in which the Geological Survey of Italy is partner. EMODnet Geology requires the compilation of a number of layers subdivided into Work Packages (WP), referring to seafloor sediments grainsize, sedimentation rates, Quaternary geology, pre-Quaternary geology and stratigraphy, coastal behavior, geological events (earthquakes, volcanoes, landslides), mineral resources. The Geological Survey of Italy is WP Leader for geological events and, in agreement with other partners, has included tsunamis, tectonics and fluid emissions among the features to be represented.

The compilation of several layers (particularly tectonics and volcanoes) suggested the possibility, based on the wealth of data acquired in the last decades and the significant improvement in instrument resolution achieved, to elaborate an updated structural model for the Italian submerged areas, in agreement with the model established on land.

Data represented in the last published version of the structural model (CNR - *Structural model of Italy,* 1983) have been updated and implemented by data and results obtained in the frame of the ongoing Italian National Geological Mapping Project (CARG), as well as by additional data collected by different national research institutions within other projects. The integration of all available tectonic lineaments with the outcomes elaborated for EMODnet-Geology (such as the map of submarine volcanoes) has led to the identification of the structural elements that represent the basic components for an updated and more complete structural model.

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Monitoring Landslides with Laser Scanner and Tromography Sperimental

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Keywords: Remote Sensing, Landslides, Laser Scanner, Seismic passive.

In March 2010, after a winter animated by prolonged heavy rains, preceded by a long rainy period, on the north-west of the University of Calabria, on the slope of Contrada Vermicelli, some landslides were activated, two of which, the most significant, are next to each other but clearly distinguished. The methods of modern geomatics, composed of a combination of different sensors and devices for the storage, transmission and processing of data of environmental type, allow us to obtain extremely detailed representations of the earth's surface, from which it is possible to derive much information useful to geological investigation. The tools and methods of Geomatics allow us to identify and classify the main structural components of an area, and to interpret their spatial correlations and dynamics, with a quantitative description of the earth's surface. Another method used in this study is HVSR (Horizontal to Vertical Spectral Ratio) this allows for evaluation of very simple oscillation frequencies for land and structures.

Distributed fracturing in reservoir-scale successions of carbonate rocks: Geological drivers and impact on physical properties

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Keywords: low-strain fractures, distributed fractures, fractured reservoirs, carbonate.

Networks of low-strain features (mode I, mode II and stylolites) are challenging scientific issues and major contributors to permeability in hydrocarbon and water reservoirs. To constrain the drivers controlling their development (stress field, lithology and tectonics) we analyse i) homogeneous, undeformed shallow water carbonates, ii) atoll-like platform with different sedimentological/mechanical units and iii) folded limestones.

In NE Brazil we have analysed outcrops of the post-rift Jandaíra Formation. To capture the regional signal and avoid local disturbances we analyse outcrops are spread over >1000km^2. Despite their flat position and lack of major folds and faults, Jandaíra carbonates are intensively fractured. Following early diagenesis and during post-rift thermal relaxation the carbonates subsided to burial depths 1 and a sub-vertical σ_2. Opening of the fracture network allowed meteoric fluids from the underlying porous Açu fluvial sandstone to migrate to the surface causing dissolution along larger fractures. With persisting subsidence, sub-horizontal stylolites formed providing the calcite which precipitated in the open fractures eventually shutting off the previous flow system. Subsequent exhumation caused the opening of pre-existing veins and stylolites.

The Middle Triassic Latemar atoll-like platform (Dolomites), shows ubiquitous distributed fracturing and only limited and well identified folding and faulting. The dominant set of fractures observed developed during subsidence in a stress field characterized by a sub-horizontal σ_1 and a sub-vertical σ_2. The horizontal, far-field compression was strong enough to over-rule the effects of the circular structure of the Latemar atoll and, as a consequence, fractures cross the various sedimentary-mechanics domains of the platform (interior, margin and slope) with no significant changes in direction. Densities and heights of fractures, on the contrary, change from one domain to the other, imposing thereby different fracture related permeability and strongly conditioning platform-scale flow.

Shallow water carbonates folded in the Alima anticline (Tunisia) provide excellent information on the role of folding. Most fractures are associated with a sub-horizontal maximum compressional stress, possibly LPS. Folding itself created a surprising limited amount of fracturing and only limited reactivation of pre-existing structures. Very widespread, on the contrary are stylolites and shear fractures associated with flexural slip.

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Semi-automatic mapping of fault rocks on a Digital Outcrop Model, Gole Larghe Fault Zone (Southern Alps, Italy)

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Keywords: faults, digital outcrop model, photogrammetry, image analysis.

The distribution and connectivity of faults and fractures control earthquake propagation and fluid flow in seismogenic fault zones. Quantifying the fault-fracture network in fossil seismogenic faults furnishes high resolution information, complementary to the data on active faults from indirect seismological techniques (e.g., Valoroso et al., 2012; Miller et al., 2004). We present a semi-automatic workflow for mapping fault-fracture traces on Digital Outcrop Models (DOMs) of the Gole Larghe Fault Zone (GLFZ), a well exposed strike-slip fault in the Adamello batholith (Southern Alps). The GLFZ has been exhumed from 8-10 km depth and consists of hundreds of individual seismogenic slip surfaces lined by green cataclasites (crushed wall rocks cemented by the hydrothermal epidote and K-feldspar) and black pseudotachylytes (solidified frictional melts, a marker for seismic slip).

A digital model of selected outcrops was reconstructed with photogrammetric techniques, using a large number of high resolution digital photographs processed with VisualSFM (Surface From Motion) software. The DOM has a resolution up to 0.2 mm/pixel and was imaged using photographs covering about 1 m^2 each. The SFM method allows to directly link each pixel in the images to the corresponding point on the DOM. We developed a MATLAB ® toolbox which extracts the fault-fracture traces from pictures in three steps: (i) fault traces from images: after preprocessing, faults are extracted using a shearlet-based edge detection algorithm (Reisenhofer et al., 2016), effective in discriminating linear elements (faults and fractures) from the isotropic texture of the wall rock; (ii) fault trace connection: collinear segments are automatically connected; (iii) supervised validation: relevant fault segments are manually selected, discarding spurious segments. The vector fault-fracture traces are then topologically corrected and projected on the DOM. The so obtained 3D fault-fracture traces are finally projected on a reference plane (parallel to the mean slip vector and perpendicular to the average fault plane).

The fault-fracture vector network is used for extracting statistical and topological relations. In particular, fracture intensity (length of fractures over area) and fracture connectivity are crucial parameters for reconstructing a reliable DFN (Discrete Fracture Network), used for modeling the fracture permeability of the fault zone.

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Structural setting and earthquake triggering of Azerbaijan mud volcanoes

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Keywords: Mud volcanoes, Azerbaijan, structural controls, seismic triggering.

Mud volcanism is a process that forces the extrusion to the topographic surface of material that originates from deeply buried sediments, such as mud, saline waters, fragments or blocks of country rock. Mud volcanoes are typically linked to in-depth hydrocarbon traps because the latter provide gases (mainly methane) and overpressured fluids that drive mud volcanism. The steep-sided conical edifices are the most typical outcome of eruptions, and may vary in height from a few meters up to hundreds of meters. The frontal sector of the Greater Caucasus fold-and-thrust belt in Azerbaijan hosts the most numerous onshore collection of mud volcanoes worldwide (around 300). Specific mud volcano features (i.e., aligned vents and elongated volcanoes) may be used as potential indicators of the orientation of subsurface feeder mud dikes, which are normally subparallel to the maximum horizontal stress S_H. Surface features have been evaluated for the Azerbaijan mud volcanoes, where the cumulative analysis of feeder dikes (and S_H directions) shows a preferred orientation between N20° and 40°E. Interestingly, mud volcanoes may be triggered off by earthquakes, producing large eruptions characterized by the violent extrusion of mud and the combustion of methane. Two nearly simultaneous Mw6.2 and Mw6.1 earthquakes hit offshore Baku on 25 November 2000. The large number of mud volcanoes, and the record of eruptions that followed these earthquakes, provide an opportunity to evaluate the effect of dynamic and static stresses on eruptions. The number of mud volcano eruptions (16) has shown a marked increase (>3 times the standard deviation from the mean) in the year following the 2000 Baku earthquakes, but, unexpectedly, the seismic events did not produce any immediate triggering of eruptions, despite the great number of mud volcanoes in the region and previous earthquakes did trigger eruptions within days of the earthquakes. Dynamic stresses are likely to play a fundamental role in the short-term triggering of eruptions, and thus the possible delayed, triggered response of mud volcanoes requires also the evaluation of the (permanent) static stress changes. The calculation and analysis of Coulomb stress changes suggests that both earthquakes would have produced normal stress changes that would have clamped the N20°–40°E-trending feeder dikes. However, many of the mud volcanoes that responded to the earthquakes have their feeder dikes suitably oriented for being unclamped. It is possible, therefore, that some of the delayed eruptions are favored in the year following earthquakes where the static stress changes cause compression of the mud source and unclamp overlying feeder dikes, 'advancing the clock' of eruptions.

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Fracture attributes in the Langhian Marnoso-Arenacea Formation of the Northern Apennines: appraisal of results from actual and virtual linear scanlines

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Keywords: Fracture scaling, Digital outcrop models.

Fracture attribute statistics is a fundamental component of modelling sub-surface porosity and permeability patterns. Field analogues provide essential information for this purpose. Depending on the type of exposures, direct data collection can be impossible or not exhaustive. In this case, photogrammetric techniques can be used to generate high-resolution digital outcrop models (DOMs) suitable to complement stratigraphic and structural field studies. We performed terrestrial and drone-aided photogrammetry on a master joint set within the Langhian part of the Marnoso Arenacea Formation (MAF), which is a foredeep siliciclastic turbidite succession largely exposed in the Northern Apennines. The outcrop selected is an about 90 m high vertical cliff in a meander of the Santerno River, where gently southward dipping strata provide the opportunity to collect joint orientation, height and spacing data from virtual scanlines in the cliff exposure and from real scanlines in the same strata, along riverbed exposures few hundred meters upstream. Comparison of data collected from field and digital outcrop models shows well comparable results, particularly when FSI (*Fracture Spacing Index*) values are considered. The results confirm the strength of this technique to investigate critical outcrops that are not directly accessible. Given the large data numbers that can be collected in digital outcrop models, once validated in the field, photogrammetric data allow robust statistical analysis to be performed on fracture attributes.

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Structural restoration and why it matters

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Keywords: Balanced cross sections, deep crustal structure, Mediterranean palaeogeography, structural interp

Structural interpretations of geological and geophysical data are rarely unique. Testing interpretations, or ranking competing ones, demands further investigation. There are several types of competing interpretative strategies used for developing tectonic knowledge in orogenic systems. Those that are phenomenologically-based can explore the complexity of the existing geological structure, illustrating this on maps, sections and in 3D. Or they can seek to show pre-tectonic configurations, perhaps supported by analogues drawn from elsewhere (e.g. seismic images of modern continental margins). Structural restoration links these two strategies by systematically relating the existing state to an inferred pre-deformation architecture, accounting for all the material involved. There are direct parallels in strain analysis where an observed (deformed) array of ellipsoids may be related, via a reciprocal strain, to a population of undeformed ellipsoids (which need not have been statistically spherical). This is more complex for the heterogeneous strains displayed in cross-sections. Even in 2D, existing algorithm-based approaches (e.g. line-length retention, trishear) represent but a tiny subset of restoration options: just because the deformation or the precursor architecture are more complex does not invalidate the general requirement to restore. Indeed the act of restoration commonly yields important further limitations on viable interpretations. This presentation explores the need to restore structural interpretations by examining crustal structure in the western Alps, and large-scale palaeogeography-based restorations in the Mahgreb of Sicily.

Crustal balancing relates estimated values of orogenic contraction to the geophysically-determined cross-sectional area (in 2D, plane strain settings) of basement to illustrate pre-orogenic variations in crustal thickness. Testing these for plausibility (e.g. using estimates of subsidence) can challenge interpretations of Alpine crustal structure. Without the restoration such interpretations are at best conjectural and devalue the underpinning geophysical data. Similar approaches may be adopted to test models of crustal stretching on modern-day rifted margins.

In the Apennine-Sicily system palaeogeographic arrangements developed in the 1980s and earlier still underpin basic structural restorations of thrust sheets and basins. They have anchored interpretations of seismic data. Structural restorations that incorporate not only the pre-orogenic but also the syn-orogenic strata demonstrate significant problems. They point to far more complex basin configurations within the region that went on to form these orogens and yield critical information on timing and rates. Restoration is the key linking strategy that allows structural geology to be integrated with other earth science elements in understanding orogenic tectonics.

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The Tuscan Nappe front in the Trasimeno area (Western Umbria): geological interpretation of a thin-skinned, Deep Water Fold-and-Thrust Belt

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Keywords: Fold-and-thrust belts, thin-skinned tectonics, foreland basins.

Modern deep water fold and thrust belts (DWFTBs) develop at both continental passive and active margins, driven by gravity and tectonic forces respectively. Despite ancient (i.e. fossil, exhumed) DWFTBs have been intensely studied for about 200 years, a detailed comparison of modern vs. exhumed case-histories is still lacking.

Here we present a multidisciplinary geological study of the Outer Tuscan Nappe (OTN), an exhumed deep water imbricate thrust system. The OTN is the object of a wide scientific literature, including recent and advanced contributes, but many dilemmas are still present, i.e i) the presence and the influence of the Ligurian units behind and above the allochtonous OTN; ii) the actual amount of shortening accommodated by the thrust system; iii) the mechanical and kinematic relationships between the basal decollement and the internal imbrication of the OTN; iv) the possible role of gravity in the OTN emplacement.

For our study we integrated surface geology data and the interpretation of a set of 2D seismic reflection profiles, crossing transversally and longitudinally the study area, from the Pratomagno1 well (also used for calibrating seismic reflectors) to the Trasimeno Lake.

Using these data, we obtained a set of transversal (i.e. WSW-ENE trending) geological cross sections, about 30 km long, showing the internal geometry of the imbricate thrust system, down to the main basal detachment, corresponding to the Late Cretaceous-Early Tertiary Scaglia Toscana Fm.. Subsequently, we performed the 2D restoration of the geological sections, using the software MOVE (Midland Valley). As a parallel activity, we also performed selected controls of key outcrops, mainly aimed at reconstructing: i) the actual transport direction during the OTN emplacement; ii) the position and offset of the subsequent, NNW-SSE trending, extensional faults dissecting the tectonic wedge; iii) the role of transversal faults, segmenting longitudinally the thrust system.

Our preliminary results show that the OTN consists of a series of thin-skinned imbricate thrusts, involving the Scaglia Toscana Fm. and the overlying Macigno Fm.. The thrusts splay out from a major basal decollement, superposing the Tuscan succession (detached from its original Mesozoic substratum) over the Mt. Rentella and Marnoso-Arenacea turbidite successions. The basal thrust becomes progressively shallower from W to E, from a depth of about 4 km to 1 km. Correspondingly, the reconstructed tectonic wedge is up to 5 km thick in its western part, and tapers progressively eastward: these values are consistent with previous estimates, based on thermal burial data. The total shortening of the imbricate thrust system is in the order of 50 km, including, at least, 30 km of horizontal ENE-ward transport along the basal decollement.

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Geological map of the northwestern portion of the Ferriere-Mollières shear zone, Argentera Massif, Italy

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Keywords: Variscan shear zone, Argentera Massif, mylonites, transpression, East Variscan shear zone.

The Ferriere-Mollières shear zone (FMSZ) is a regional shear zone cross-cutting the whole Argentera Massif (Western Alps). It separates two migmatitic complexes: the Tinèe complex and the Gesso-Stura-Vesubiè complex. Both metamorphic complexes are made by high-grade migmatitic gneisses (Compagnoni et al., 2010). Permo-Triassic sediments lie unconformably above the Varisican basement and are separated to the overlying Helvetic-Dauphinoise sediments by a tectonic contact. Mylonitic rocks of FMSZ mainly consist of mylonitic gneiss and micaschists interlayered with mylonitic leucogranites. Geological-structural mapping performed at 1:10000 scale of the area between Ferriere village and Vallone del Piz focused on the characterization of mylonitic deformation in the northern portion of the FMSZ. Mylonites have been classified according to the percentage of matrix and porphyroclasts (Sibson, 1977; Passchier & Trouw, 2005). Mylonitic foliation strikes N110-130 and dips 70-90° toward NE, while mineral lineation trends N120-130 plunging 20-30° to the NW. Dextral top-to-the SW sense of shear indicators have been identified. A deformation gradient has been observed towards the core of the shear zone marked by the occurrence of ultramylonites and minor phyllonitic layers. The outer zones are characterized by the development of protomylonites gradually passing to unsheared migmatites. Low-angle greenschist-facies shear zones cross cutting the previous mylonitic foliation with a reverse top-to-the S and top-to-the SW sense of shear were also recognized. Detailed geological mapping, structural and petrographical analysis allowed to identify and to map different types of mylonites and deformation gradients within the FMSZ. It is possible to infer that the FMSZ is a Variscan transpressive shear zone activated under amphibolite facies metamorphic condition and that it subsequently experienced a syn-shearing retrograde metamorphism. The Shear zone has been reactivated under greenschist-facies metamorphic condition during Alpine Orogenesis (Sanchez et al., 2011). This event is however limited to shear zones with reverse top-to-the SW kinematics.

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Contouring approach to 3D geological model building from subsurface "vintage" data

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Keywords: 3D validation, contour maps, cut-off lines, intersecting faults.

A simple procedure to build consistent 3D geological models from subsurface sparse "vintage" data is presented. The methodology was developed using MOVE (Midland Valley) to reconstruct the structural setting of the Campidano graben, where the data available are three wells and several 2D seismic sections acquired during '60s and '90s.

Once that the geodatabase has been arranged, the well-logs and seismic lines interpreted and calibrated and the horizons and structures picked, the typical method to build the 3D geological model is the surface interpolation of the faults and horizons lines picked in the seismic profiles. Differently, our approach is to use the faults and horizons interpreted in the seismic sections to construct a map with the contour lines of both faults and horizons and the cut-off lines. The cut-off lines must be built honouring the intersection points between the horizons and faults contour lines. Once that the TWT values are assigned to the equivalent contour lines, the 3D model is built following these steps: 1) fault surfaces building by interpolation of the fault contour lines; 2) projection of the cut-off lines onto the fault surfaces; 3) horizon surfaces building by interpolation of both the horizon contour lines and the projected cut-off lines.

Some benefits arise from building the fault and horizon surfaces interpolating the contour lines rather than the lines picked in the seismic profiles. They are: i) to build reliable surfaces no matter if the lines interpreted in the seismic profiles display apparent or true dip; ii) to detect structures striking parallel to the seismic profiles, often source of unrealistic geometries and seismic misinterpretation; iii) to have more control in reconstructing structures in areas not covered by data; iv) to recognize hidden structures not recorded in the analyzed seismic sections; v) a major quality control of 3D model at the intersection between more faults by using cut-off lines relationships.

To conclude, the contouring approach to 3D model building allows to have a geometrical control in the whole studied area despite the scarcity of data and to visualize 3D surfaces built starting from contour maps that are themselves 3D objects, although displayed in map view.

Furthermore, the 3D model built following this approach could be a reliable and consistent starting point for subsequent additional processing like rigid-block restoration in map view, extension and shortening evaluation, paleo-stress field reconstructions.

Along-axis variability of continental rifts: examples from the Main Ethiopian Rift

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Keywords: Continental rifting, rift obliquity, Main Ethiopian Rift.

Continental rifts often reveals considerable along-strike variations in architecture and evolution as well as other characteristics such the volumes of extruded and intruded igneous rocks. These variations may be the result of variations in parameters such as preexisting plate architecture (inducing variations in crustal and lithospheric thickness), rift width, rate and kinematics of extension. The Main Ethiopian Rift (MER) in East Africa is a typical example of a complex continental rift, where the influence of these different parameters on the along-axis variations in rift characteristics can be analyzed in detail. In this contribution, I first review the fault pattern, the evolution of deformation and the density volcanic vents in the different MER sectors. I then compare them with existing geophysical and geological data to provide insights into the main controlling factors on rifting in the MER. This comparison suggests that along-axis variation in rift kinematics, from orthogonal rifting in the Southern MER to moderate obliquity in the Northern MER plays a major role in controlling the along-axis variations in rift architecture, evolution and volcanicity. In particular, rift obliquity plays an important role in localizing deformation in narrow, axial zones of internal faulting, promoting an efficient thinning of the lithosphere. This is in turn expected to correspond to an increase in decompression melting, promoting an increase in magmatism in oblique segments of the MER.

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Mud volcanoes fields on Mars: clues and proxies for the identification

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Keywords: Mud Volcanoes, Methane, Fluids Circulation.

The recently observed presence of methane in Martian atmosphere (Geminale et al., 2008; Mumma et al., 2009) could be a crucial clue to find and analyze environments that can host life on Mars. The origin of methane is still debated, many mechanisms, both biogenic and abiogenic, can contribute to its release such as: methanogens bacteria, destabilization of clathrates, volcanic degassing or indirect release from subsurface traps. On Earth, mud volcanoes are mainly associated to the degassing phenomenon (e.g. Skinner and Mazzini, 2009) and mud volcanoes-like features have been widely recognized on Mars (e.g. Skinner and Tanaka, 2003; Allen et al., 2009). Mud volcanoes possess the pivotal characteristic to be water-related features, therefore fluids circulation turns up to be a crucial topic to investigate. For example, disregarding biological implications, the circulation processes themselves can destabilize methane traps, extract and release gasses into atmosphere (Kargel et al., 2007). Additionally, mud volcanoes are not high T-P environments and so unaltered biomarkers-material can be moved from the depth toward the surface (Oehler and Allen, 2009). Moreover, mud volcanoes, as magmatic volcanoes, can be exploited to infer fractures' direction and obtain clues about the depth of the pressurized sources (Bonini and Mazzarini, 2010). These geological settings are going to be preferential location for the future surface observations within the TGO (Trace Gas Orbiter) ExoMARS mission seeking for evidences of habitability on Mars.

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Earth's tides, plate motions, graviquakes and elastoquakes

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Keywords: Plate tectonics, driving mechanisms, graviquakes, elastoquakes.

Tectonic plates move "westerly" along a flow described by the so-called "tectonic equator". This great circle is inclined about 30° relative to the geographic equator and mimics the inclination of the Moon's revolution. We infer that this geometric and kinematic feature is an indication of the active role of the Earth's tides in driving plate tectonics. The drag exerted by the tidal lag and the permanent oscillation of the solid Earth tide should coexist and contribute with the thermal cooling that allow and control mantle convection. In fact upper mantle circulation is polarized "eastward", whereas subduction zones contribute to mantle convection with three times larger volumes of recycled lithosphere along W-directed slabs. The pump provided by the horizontal component of the solid Earth tide is inferred as the effective mechanism determining plate motion and the net rotation of the lithosphere decoupled at the low velocity layer with respect to the underlying mantle. Therefore, the horizontal component of the Earth's tide determines day after day the accumulation of stress gradients at plate boundaries. The vertical component of the Earth's tide may rather trigger the dissipation of energy throughout earthquakes once the threshold of failure is reached in varying the lithostatic load with the oscillation of g. However, this mechanism is opposite as a function of the tectonic style. In fact during the low tide, g is higher, increasing the lithostatic load and most frequently triggering the activation of normal faults. Alternatively, the high tide has lower g value and the lithostatic load acting on faults decreases, possibly favoring the activation of thrusts. Since normal faults mostly dissipate gravitational potential energy, they are classified as graviquakes, whereas thrust faults release elastic energy and are therefore defined as elastoquakes. This differentiation is required in order to start recognizing the different phenomenologies associated to the earthquakes as a function of the tectonic setting.

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Kinematic characterization of Plio-Pleistocene faults located in the western flank of Domuyo volcano (Neuquen, Argentina) and its relationship with the geothermal springs of the area

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Keywords: Domuyo Volcano, Geothermal Springs, Plio-Pleistocene faults.

The Domuyo volcano is located at 36°38’ Latitude S and 70°26’ Longitude W, in the northern extreme of the Cordillera del Viento. This morphoestructural unit represents a large basement block, orientated N-S, and exhumed in different compressive stages during the Andean Orogeny. It represents the internal section of the Chos Malal fold and thrust belt (Folguera et al., 2010).

We have collected kinematic data from Neogene and Quaternary units, which are located on the western flank of Domuyo Volcano. The measuring stations are located in the areas of Rincon de Las Papas, Villa Aguas Calientes, Cerro La Guitarra y Cerro Ventoso. The kinematic data from each station was processed with FaultKinWin *software (*Allmendinger et al., 2012), using the graphic method based on Bingham Statistical Distribution (Marrett & Allmendinger, 1990), in order to obtain the three principal axes of the deformation ellipsoid ($\lambda 1$, $\lambda 2$ and $\lambda 3$), and their orientation. The Bingham method allows one to calculate the direction and magnitude of maximum compression and extension axes (P&T axes), graphically obtained from a kinematic data group.

The difference between the orientations of the principal axes associated with units of different ages, are statistically significant, and closely related with the different stages of deformation during the tectonic evolution of the area. For faults associated with Neogene and Quaternary units, there is a clear signal of ENE-WSW extension (average: T-axes: 60°/8,6°NE).

Although there are no reports of extension with a general ENE-WSW orientation during the Upper Pleistocene for the region, the preliminary results suggest that more detail studies in other areas are needed, in order to better define temporarily and spatially this extensive event. The possible tectonic process that could cause this final field of forces could be local and be related to the collapse of the Domuyo-Cerro Domo Complex. Or they could be related to a regional tectonic process, for example, the tear of the subducted Nazca plate, which is possibly responsible for the Fosa de Loncopué development, located in the south of the study area (Rojas Vera et al., 2014).

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Investigation of two non-parallel fault systems on Mercury

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Keywords: Mercury (planet), lobate scarps, buffered crater counting, kinematic analysis, planetary geology.

The recent completion of the geologic map of the Victoria quadrangle 'H02' (Galluzzi et al., 2016) has led to significant insights on the structural framework of this area of Mercury, revealing the presence of at least two main non-parallel fault systems. Inside the H02 area three main systems were identified and their orientation was statistically defined through rose-diagram analysis: the N–S 'Victoria system' (VS), the NW–SE Carnegie Rupes system and a less prominent NE–SW system found in the area of Larrocha crater ('Larrocha system', LS). The Victoria–Antoniadi array defines a central longitudinal tectonic fault-free bulge limited to the west by Carnegie Rupes and other Carnegie system east-dipping faults, which are inferred to be kinematically related and antithetical to the VS faults. Repeated measures done using faulted craters as kinematic indicators (Galluzzi et al., 2015) were used in these areas for a finite strain inversion analysis of the entire fault system resulting in a shortening axis trending 71°E. To the west of the bulge, the LS faults are more degraded, thus no craters permitted to assess their geometry. Along the west limit of the bulge, some LS segments seem to accommodate the transition between some minor VS segments in a manner similar to the relay ramps observed in terrestrial fault systems (e.g. Peacock & Sanderson, 1995). The buffered crater counting method (Tanaka et al., 1982) was used to assess the age of the VS and LS. Preliminary results give an average age of ~3.77 Ga for both systems. This result may suggest that the LS encompasses second order NE-SW fault segments linked to the same tectonic event that developed the more prominent (i.e. first order) N–S faults pertaining to the VS. Are these systematic alignments due to crustal or mantle discontinuities? The Victoria–Antoniadi array is characterised by the presence of volcanic vents defining three peculiar spots along the array that correspond to systematic changes in fault zone segmentation, implying a strict relationship between volcanic activity and faulting in this area. A deeper knowledge of Mercury crustal or mantle discontinuities is required to further investigate this case.

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A semiautomated procedure to evaluate discontinuity characteristics of unstable rock masses. The case study of Brusson and Roisan rock slopes (Aosta Valley, Italy)

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Keywords: Rock fall, Structural analysis, Terrestrial laser scanning, Rock mass discontinuity, Risk analysi

The need of efficient interventions more and more consistent is fundamental in the mountain environment, where instabilities as rockfalls are frequent. The goal is to mitigate the risk and to ensure the safety of people along roads and in the residential areas. We aim to define a methodology based on an semi-automatic workflow, that allows the characterization of a site with critical issues related in particular, to rock falls. The aim is starting from the extraction of the rock discontinuities to reach the assessment of Rock Unit Volume by 3D survey technology. The increasing precision of 3d acquisition technology as Laser Scanners and terrestrial photogrammetry makes possible a detailed structural and geomorphological analysis of a rock slope never before achieved.

The developed methodology could be a part of the risk management measures for a rock fall event. Therefore the study results will provide scientific basis that the public Administration can use in the management of structural and non-structural interventions for risk mitigation and for planning stabilization works.

The territory in which are located the test sites is the region of Valle d'Aosta (north western part of Italy), where landslides and rock falls are widespread events. In particular in this mountain area in recent years, rock fall risk management plays more and more an important role in territorial plannig, due to some occurred lethal accidents. Rock falls occur for detachment and fall of rocks from a very steep slope. The material involved drops in free fall until it reaches the slope and after the impact, its activity continues in bouncing and rollings.

The rock falls are characterized by a high hazard and a remarkable destructive capacity and frequently involve human activities and structures.

Test sites belong to portions of land largely invested by this problem and in both cases, rock falls affect roads and buildings. We selectd the big slope located on Regional Road 28 to Valpelline (Bois de Rachau) in the Municipality of Roisan and the Vollon site in the Municipality of Brusson.

The slopes have been represented with the creation of point clouds obtained from surveys with Terrestrial Laser Scanner (TLS), the Riegl VZ-4000 model (kindly granted for research purposes by ISE NET Srl, Spin Off of Politecnico di Torino) with triple-frequency GNSS receiver (Leica GS25), and by terrestrial and drone photogrammetry (Prof. Andrea Lingua, Politecnico di Torino.).

The method allows the characterization of the discontinuities of a rock face potentially collapsing, thanks to the TLS and TDP technology, avoiding the use of rock climbers for the geological survey in the rock slope; lowering the risk of accidents (safety factor); obtaining measurements on rough and not accessible areas (accessibility factor); performing data analysis and obtaining reliable results with open source software (reliability factors); achieving reliable information to quickly plan stabilization actions.

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Dating thrust systems on Mercury: new clues on the thermal evolution of the planet

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Keywords: structural geology, thrust system, Mercury, dating.

The global tectonic scenario of Mercury is dominated by contractional features mainly represented by lobate scarps. These structures are the expression of surface-breaking thrust faults and are linear or arcuate features widely distributed on Mercury. Since they display a broad distribution of orientations, lobate scarps are thought to be related to a global contractional strain, associated to planetary cooling (Watters et al., 1998, Geology, 26, 991–994). The age determination of these features will contribute to better constrain whether limits could be placed on when the contraction occurred. For these reasons we dated two thrust systems, located in different regions of Mercury. The first system is located at the edge between Kuiper and Beethoven quadrangle (latitude 9°20'N-23°42'S and longitude 72°73'-59°52'W). These 1500-long thrust system is constituted by several lobate scarps with a NNE-SSW orientation and a prevalent westward vergence. The second thrust system considered in this work is the Enterprise Rupes, a 820 km-long scarp system that cut the Rembrandt basin.

We dated the activity of these systems through the buffered crater counting technique (Fassett and Head, 2008, Icarus, 198, 37–56; Giacomini, et al, 2015, GSL, 401, 291–311) which can be used to derive absolute model ages of linear landforms such as faults, ridges and channels. The results gave comparable ages for the two systems and suggests that the activity along major rupes all around planet Mercury have most probably begun before 3.5 Ga. This will give us new clues to better understanding the thermal evolution of the planet.

The role of anisotropy in the mechanics of faulting: an integrated field and laboratory approach

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Keywords: Mechanical multilayer Fault Rock Mechanics.

Carbonate multilayers characterized by the presence of several intervening clay-rich layers act as sealing horizons. The development of fractures and faults within these mechanically heterogeneous multilayers can strongly influence their sealing capability. However, the geometrical complexity of these faults is still not fully mechanically understood. Here we investigate fault initiation and evolution integrating field observations on outcropping faults affecting a mechanical multilayer and rock deformation experiments. Outcropping faults initiate with a staircase trajectory that partially reflects the mechanical properties of the involved lithologies, as suggested by triaxial and biaxial deformation experiments. However, some low angles of fault initiation in limestones (i.e. θ_i = 5°-20°) and high angles in marls (i.e. θ_i = 45°-86°) suggest that structural inheritance plays an important role at the onset of faulting. In our case study, structural inheritance results from pre-existing joints within limestones and sedimentary foliation within marls. The progressive fault growth involves the development of a well-organized marly foliated fault core that embeds sigmoidal fragments of limestone. The angles of fault reactivation that concentrate between 30° and 60°, consistently with the low friction coefficient measured in our laboratory experiments (μ_s = 0.39), indicate that clay minerals exert a main control on fault friction. Moreover, the presence of calcite mineralization in all the investigated faults suggests that fracturing and faulting are the main mechanisms allowing for fluid circulation within the carbonate multilayer, as further supported by triaxial experiments showing the onset of a fluid flow only after the development of a thoroughgoing fracture within the experimental sample. Our integrated analysis suggests that incipient faults with a staircase trajectory promote fluid flow mainly at dilational jogs, i.e. almost parallel to the bedding and confined within competent layers, and along slip surfaces only during slip events. With accumulating displacement the development of a low-permeability foliated fault core allows for fluid flow only during fluid-assisted fault reactivation. Thus, the sealing integrity of the clay-rich multilayer can be compromised only by the activity of larger faults cutting across its entire thickness.

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3D free-air gravity anomaly modelling approach for a structural investigation of the Southeast Indian Ridge

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Keywords:Gravity data, Indian Ocean, Oceanic Crust.

In this study we analyzed the free-air gravity anomalies measured on the northwestern part of the Southeast Indian Ridge (hereafter SEIR) during the BGR cruise INDEX2012 with RV FUGRO GAUSS.

The survey area covered the ridge from the Rodriguez Triple Junction along about 500 km towards the SSE direction.

The Rodrigues Triple Junction (RTJ) near 70.00° E, 25.30° S, is the joining point of the intermediate-spreading Southeast Indian (SEIR) and Central Indian Ridges (CIR) with the slow-spreading Southwest Indian Ridge (SWIR). The SEIR, close to the triple junction is a typical intermediate spreading rate ridge (2.99 cm a^{-1} half rate) trending N14O°.

During INDEX2012, gravity and magnetic data were measured along 65 profiles with a mean length of 60 km running approximately perpendicular to the ridge axis. The final gravity data were evaluated every 20 seconds along each profile. This results in a sampling interval of about 100 m. The mean spacing of the profiles is about 7 km. Together with the geophysical data also the bathymetry was measured along all profiles with a Kongsberg Simrad EM122 multibeam echosounder system.

To consider the regional gravity field we extended the length of each profile to the area outside the ridge, integrating INDEX2012 shipborne gravity data (Heyde, 2013) with low resolution gravity data derived from satellite radar altimeter measurements (Sandwell and Smith, 2009, version 19.1, referred to as SDW19.1). For the extension of the bathymetric data the GEBCO08 dataset (GEBCO, 2010) was used.

We analyzed the gravity signal along those 2D sections which cross particular geological features (uplifted areas, accommodation zones, hydrothermal fields and areas with hints for extensional processes e.g. OCCs) in order to establish a correlation between the gravity anomaly signal and the surface geology.

Implementing a forward modelling approach using IGMAS+ geo-modelling software (Interactive Gravity and Magnetic Application System) we built a conceptual 3D geological density model of the subsurface setting of the studied area.

We assumed the density values of these bodies considering the relation between the density and the seismic P-wave velocity V_P. We choose the velocity data from the scientific literature.

We started with a simple layered geologic model consisting of four density bodies (which represent the sea, upper oceanic crust, lower oceanic crust and the upper mantle) with constant thickness and density. We did not include the sediment layer considering that in the study area the oceanic crust is young.

We found that this model does not explain the measured anomalies satisfyingly and further changes have to be considered for the area beneath the ridge axis. In particular we reduced the density values of the lower crust and the upper mantle beneath the axial ridge introducing in the model two additional bodies called partial melted crust and anomalous mantle.

We created isobaths map of the anomalous mantle beneath the axial ridge extracting the mantle depth from the 3D model. These maps highlight the lateral heterogeneity of the oceanic crustal structure beneath the ridge axis. In particular there are areas characterized by crustal thickening related to magmatic accretion and areas of crustal thinning, related to depleted accretion of the mantle, where extensional processes can lead to the exposure of OCCs. These areas could host potential hydrothermal vent fields.

The interpretation of gravity data at this scale can be really helpful as a preliminary exploration because it could lead to the identification of interest areas for mining in the future.

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Structural setting of the eastern sector of the Caloris basin, *Shakespeare* Quadrangle (H03), Mercury

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Keywords: Planetary geology, Mercury, tectonics, thrust and wrinkle ridges, structural analysis.

The remotely sensed images of Mercury's surface, acquired by two NASA probes (Mariner 10 and MESSENGER), revealed a moderately cratered surface characterized by the occurrence of three main type of plains materials and lunar-type landforms (Strom *et al*., 1975).

Using the MESSENGER images, we investigated trend and kinematics of the structures in the eastern side of the Caloris basin (H03 Quadrangle), the most prominent geo-morphological feature on the planet. Based on the dominant contractional nature of Mercury's tectonics (Byrne *et al*., 2014), the structures have been interpreted as thrusts, when they show a relevant break in slope, or mapped as wrinkle ridges when break is less evident and they occur within smooth plains materials and basins.

The ~N-S oriented Schiaparelli Dorsum is a typical planetary wrinkle ridge (Watters & Nimmo, 2010) which extends across H03 and H07 quadrangles for ~420 km length. It appears as a broad asymmetric morphological culmination that shows several surface breaks along the western steeper slope, suggesting this is a fault-controlled scarp produced by the westward propagation of several thrust segments, and coaxial wrinkle ridges along the eastern gentle slope, probably produced by back-thrusts propagation. Southwards it displays a wedge bounded by conjugate thrust faults describing a pop-up structure.

Azimuthal analysis of the structures shows two preferential orientations for thrust segments: to the NE of Caloris, the main trend of thrusts is ~N40°E, whereas the wrinkle ridges are mainly aligned ~N10°E. To the E of Caloris, the preferential trend for both kinds of structures is ~N-S. In order to date the structures, preliminary analyses have been performed on Schiaparelli Dorsum, using the "buffered crater-counting" technique (Tanaka, 1982), which allows to derive the age using the density of thrust-superimposed impact craters.

The adopted technique allows to improve the accuracy of dating linear features with respect to the classical methods based on stratigraphic and cross-cutting relationships between structures and adjacent geologic units. Understanding the patterns and timing of faulting can significantly improve the knowledge of the past stress state of the planet.

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Pre-Pliocene fault networks deciphered after 3D geological modelling of the Monte Alpi area, southern Italy

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Keywords: Monte Alpi, 3D modelling, Apulian Platform, Messinian Tectonics.

The Monte Alpi is made of Mesozoic carbonates, pertaining to the Apulian Platform, topped by a mixed carbonate-terrigeneous sedimentary succession, which represents the infill of a Messinian shallow-water foredeep basin. The latter was located at the front of the propagating fold-and-thrust belt. The Messinian sedimentary succession includes a 35 meters thick Lower Messinian interval, paraconform over the Mesozoic carbonates, and a 350 meters thick Upper Messinian interval lying in pronounced angular unconformity on the Lower Messinian-Mesozoic bedrock.

Recently, several models were proposed to explain the structural evolution of Monte Alpi. Among those, one is consistent with the Monte Alpi being a large push-up structure related to the Quaternary activity of a large, NW-SE striking, left-lateral strike-slip fault zone. Contrarily, others envision that, afteruanterqq Lower Pliocene orogenic wedging and Upper Pliocene thin-skin extension of the allochthon, the Apulian carbonates of Monte Alpi were first involved in Upper Pliocene-Lower Pleistocene compression and in subsequently Middle Pleistocene-Holocene exhumation due to extensional faulting.

All models do not address the possible role exerted by pre-existing structural discontinuities. In particular, none mention the faults active during Upper Miocene foreland bulging and subsequent along foredeep stretching. Indeed, as suggested by results of field and laboratory analyses, textural, compositional and thickness variations in the Upper Messinian sediments are consistent with activity at that time of a high-angle network of NW-SE and ENE-WSW extensional faults.

In order to decipher the attitude, kinematics and dimensional properties of the pre-Pliocene faults, we performed a 3D geological model of the Monte Alpi and surrounding areas. The model (GocadÒ software), involved first the build up of several stratigraphic horizons and fault planes by using a Discrete Smooth Interpolator. A volume of 2.10^3 km^3 was modelled with 16 stratigraphic and 46 fault surfaces, enabling attitudes, lengths and throws to be computed for the wider fault surfaces.

Finally, 3D restoration along vertical lines was performed, along faults cropping out in Monte Alpi and interpreted as active during Messinian times. Hence, the vertical displacements was computed for each Messinian fault taking into account the lower Messinian stratigraphic horizon. In this way we restored the sub-horizontal surface of the Top Cretaceous of the Apulian Platform. We therefore, differentiated the geometry of the pre-Messinian fault network, which dissected the Jurassic-Cretaceous boundary from the Messinian fault network.

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Quaternary activity of the Pede-Apennine Thrust (Emilia-Romagna, Italy): multiple evidence of recent deformations

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Keywords: Pede-Apennine Thrust, Quaternary, OSL, Lower Emilia-Romagna Synthem.

The activity of the Pede-Apennine Thrust system (PAT), which bounds the morphological Pede-Apennine margin (Emilia-Romagna, Northern Italy), has been debated during last decades and has been considered either active or inactive by many authors. If considered active, the hazard associated to the PAT activity should be addressed, given the proximity of this structure to a densely populated area, such as the Po plain. According to the necessity of a better definition of this problem, by means of a multidisciplinary approach, we carried out the analysis of this structural element in a sector spanning about 50 km along the Pede-Apennine margin, comprised between the Panaro and the Enza river valleys. In order to highlight the recent PAT activity, we integrated structural, sedimentological and pedological field data. We report structural evidence of PAT activity during Pliocene up to the Middle Pleistocene: reverse faults were observed in the Argille Azzurre formation, and in the sandy-clayey portion of the Lower Emilia Romagna Synthem, constituting a direct evidence of deformation. Furthermore, by means of OSL dating on deformed soil profiles observed above the Ghiardo terrace (North of Quattro Castella), we can infer a tectonic pulsation that occurred during the Late Pleistocene (about 60-80 kyr), responsible for the partial margin sediments erosion and re-deposition in a small basin elongated parallel to the margin itself. Scattered activations of PAT-related structures can be considered responsible for the drainage diversion observed in paleo-channels belonging to the Lower Emilia Romagna Synthem deposits, nowadays outcropping in sections along some major river valleys (eg. Secchia, Enza and Panaro river valleys). We propose that, due to the alternated activity of PAT and its external splay thrusts, the streams were forced to orientate their flow roughly parallel to the margin, resulting in channel segments roughly striking W-NW to E-SE. In addition, we use the field evidence to generate numerical models of the PAT deformation by applying the "Trishear" mechanism (Erslev, 1991). Deformation rates have been extrapolated along two transects located near Quattro Castella and Scandiano. This analysis has allowed us to estimate slip rates of ca. 0.68 $mm \cdot yr^{-1}$ and ca. 0.70 $mm \cdot yr^{-1}$ (over the last 1.2-0.8 million years) for the Quattro Castella and Scandiano transects, respectively.

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Formation and reactivation of rifted margins: what is the role of inheritance?

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Keywords: rifted margins, reactivation, inheritance, Alpine Tethys, Atlantic.

Assessing the importance of inheritance in controlling the bulk rheology of the lithosphere, the deformation history of tectonic systems and the related processes is a long-standing problem in Earth Sciences. In contrast to physical laws that are generally valid, inheritance is not and consequently cannot be integrated in a model without having insights into the history of the investigated geological system. Moreover, inheritance can, but does not have to control tectonic systems.

We use the term inheritance to refer to the deviation between an "ideal" layer-cake type lithosphere and a "real" lithosphere containing heterogeneities. 3 types of inheritance can be defined, namely structural, compositional and thermal inheritance. The aim of our presentation is (1) to provide a conceptual framework about how inheritance may control the architecture and evolution of rifted margins and their reactivation during subsequent convergence; (2) to identify the role of inheritance during formation and reactivation of rifted margins; and (3) to define its relative control on the deformation and rheological evolution from the micro-scale to the outcrop scale to the seismic scale.

In the presentation we will focus on three well-studied rift systems that are the Iberia-Newfoundland, the Pyrenean-Bay of Biscay and the Alpine Tethys rift systems. All these rift systems went through a stage of hyperextension and show variable amounts of reactivation ranging from incipient to complete. For these examples, we can show that the strain evolution and localization of deformation during the early stages of rifting is controlled to first order by the distribution and thickness variations of ductile and brittle layers, inherited from the initial composition and thermal structure of the lithosphere. However, at more advanced stages of rifting, once the crust is less than 10km thick, deformation can be controlled by the presence of fluids and the breakdown reactions of feldspar and olivine to weaker hydrated minerals (e.g. clay, serpentine), and/or by the presence of magma. How these processes can modify the rheology and control the final stages of rifting remains unclear. In addition, it is important to note that the location of final lithospheric breakup is not always controlled by inherited structures. This seems to contrast with the onset of reactivation, which appears to be controlled by the presence of weak decoupling horizons that are inherited from the formation of the rifted margin and are preferentially reactivated during subsequent convergence.

Understanding how far the new ideas and concepts derived from the southern North Atlantic and Alpine Tethys can be translated to other less explored rift systems and mountain belts will be one of the challenges of future research.

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Geology of the Raditladi quadrangle, Mercury (H04)

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Keywords: Planetary geologic map, H04 Raditladi quadrangle, Mercury.

In this work we present the 1:3,000,000-scale geologic map of the Raditladi quadrangle (H04) of Mercury (22.5-66° N, 90-180° E). The area covers more than 5x10^6 km^2 (nearly 7% of the entire planet) and encompasses several features of interest such as the Caloris basin, the Raditladi basin, hollow clusters and volcanic features. The mapping took advantage of the data produced during MErcury Surface, Space ENvironment, GEochemistry, and Ranging spacecraft (MESSENGER) orbital phase. The mapped deposits include impact-related units observed at several scales from the Caloris basin to the secondary crater chains. The Smooth Plains unit covers the majority of the area, mantling the older Intercrater Plains and Bright Intercrater Plains units. Crater counting achieved on the catalog of craters larger than 10 km produced during mapping, allowed for the definition of the ages of the main units and for the timing of the Caloris impact. Results show that the emplacement of all the main units and the Caloris impact event, representing the main geologic events in the quadrangle, were concentrated between 3.96 and 3.72 Ga. After this intense phase, the geologic framework was modified only by local events like impact craters and hollows formation. We mapped tectonic, cooling-driven and impact-related structures all over the area. This map is among the first products for the detailed geologic characterization of Mercury at such scale. It will contribute as a constraint and a support for both, further local investigation and mapping, and targeting of the forthcoming BepiColombo ESA/JAXA joint exploration mission to Mercury.

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Partitioning of deformation in multilayers characterized by multiple décollements with either frictional or viscous rheology: insight from analogue models

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Keywords: evaporites, rheological behaviour, décollement layers.

The vertical distribution and rheological behaviour of mechanically weak layers alternating with stronger ones plays a key role in determining how contractional deformations are accommodated at convergent plate boundaries. In the upper crust, evaporites typically provide preferential décollement layers for thrust localization and foreland ward propagation, thus significantly influencing evolution of thrust-fold belts in terms of mechanical balance, geometries, and chronological sequences of faulting. Evaporites occur at the base of many passive margin successions that underwent positive inversion within orogenic systems. They typically produce salient in deformation fronts, as in the Jura Mountains, the Salakh Arch in the Oman Mountains, or the Ainsa oblique thrust-fold belt in the Spanish Pyrenees. Evaporites frequently occur also in foredeep deposits, as in the Apennines, the Pyrenees, the Zagros etc., causing development of additional structural complexity. Low-friction décollement layers also occur within sedimentary successions involved in thrust-fold belts and they contribute to the development of staircase fault trajectories. The role of décollement layers in thrust wedge evolution has been investigated in many experimental works, particularly by sandbox analogue experiments that have demonstrated the impact of basal weak layers on many structures of thrust wedges, including the dominant fold vergence, the timing of fault activity, and the critical taper. Some experiments also investigated on the effects of weak layers within accreting sedimentary successions, showing how this triggers kinematic decoupling of the stratigraphy above and below the décollements, with disharmonic deformation. However, at present a systematic experimental study of the deformation modes of an upper crustal mechanical stratigraphy consisting of both low-friction and viscous décollement layers is still missing in the specific literature. In this work we present the results of such a study, where a three-décollement mechanical stratigraphy has been deformed in the sandbox at the same boundary conditions. Different rheological properties were assigned to the three décollements in different experiments, up to testing all possible mechanical stratigraphies. Implications on thrust propagation and slip rate history and cross-sectional thrust wedge architecture are discussed and compared with natural cases.

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Facies-related fracture patterns in the Marnoso-Arenacea Fm. turbidites, Northern Apennines, Italy

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Keywords: Folding-related fracturing, turbidite, Marnoso Arenacea, physical stratigraphy, fracture stratigr

Natural fracture patterns are a fundamental parameter governing subsurface fluid flow and, consequently, they exert a primary control on resources like aquifers, hydrocarbons and geothermal reservoirs, and on environmental issues like CO_2 storage and nuclear waste disposal. In layered sedimentary rocks, depositional processes imprint rock rheology and favour the development of both mechanical anisotropy and heterogeneity on a wide range of scales. This is expected to strongly influence the location and frequency of fractures, adding to folding and faulting processes and thus increasing the difficulty of providing reliable predictions for subsurface reservoirs. The impact of the depositional imprint on fracture patterns is expected to be maximized in turbidites, due to their strong three-dimensional variability in both sedimentary structures and stratigraphic patterns. To better constrain the contribution of stratigraphic, sedimentological and petrophysical attributes, we performed a high-resolution, multidisciplinary study on a selected Langhian stratigraphic interval of jointed foredeep turbidites in the Miocene Marnoso-arenacea Formation (Northern Apennines, Italy), which are characterised by a great lateral and vertical variability of grain-size and depositional structures. We demonstrate that statistical relationships among field and laboratory data significantly improve when the single facies scale is considered. Moreover, for similar facies recording different evolutionary stages of the parent turbidity currents, we observed a direct correlation between the three-dimensional anisotropies of rock hardness tensors and the normalized fracture frequencies, testifying for the primary sedimentary flow-related control on fracture distributions.

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From geological surface data to the interior of a comet: modelling the stratified structure of 67P comet based on scattered attitude observations

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Keywords: 67P, Rosetta, implicit modeling.

On august 2014 the Rosetta spacecraft was successfully inserted into the orbit of the bilobate comet 67P/Churyumov-Gerasimenko (67P). Since then a large number of images of the comet were taken by the onboard OSIRIS camera system, providing evidences for a variegated and complex morphology of the comet surface.

A continuous and pervasive stratification of the nucleus has been proposed as explanation for morphological terraces distributed all over its surface (Massironi, 2015), which are then interpreted as cuesta-like structural features, implying some kind of large-scale dishomogeneity in terms of strata resistance to the shaping agents acting on the comet.

We computed the best fitting planes for more than 200 terraces, using the vertices of the 3d shape model of 67P. These planes constitute the only measurable source of information about the stratified nature of the comet, given other features (e.g. strata traces on vertical cliffs) are difficult to follow globally.

We then developed an implicit model of the comet layering, one for each lobe, based on the assumption of a thickness-preserving stratification with ellipsoid-derived shape. The code was developed ad-hoc given most of implicit modelling software would not easily handle this highly specific case.

This model was then fitted to the attitude observations providing a numerical model capable of predicting stratigraphic depths and strata attitudes for each point on the comet surface and its interior. Model predictions has been successfully validated with surface observations from OSIRIS pictures and with the effective slopes on the comet suggesting the presence of more resistant strata.

This work constitute a remarkable example of a feedback to the planetary sciences, directly coming from methods applied in structural geology.

Massironi M. et al. 2015. Two independent and primitive envelopes of the bilobate nucleus of comet 67P. Nature, 526, 402-405.

3D structural modelling of buried high-angle faults in Apulian carbonates, inferences on timing, kinematics and mechanisms of faulting

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Keywords: 3D geological modelling, southern Apennines, Apulian carbonates.

3D geological modelling is an useful tool to obtain the accurate geometry of buried geological structures. Such a modelling is often performed by integrating different types of data, for instance well logs, seismic reflection profiles, etc. In this work, which focuses on the buried Apulian carbonates beneath the Bradano foredeep sedimentary infill of southern Apennines, the results of a 3D geological modelling carried out by mean of the Move^{TM} software are presented and discussed in terms of age, kinematics, and growth mechanisms of the high-angle fault network.

The 3D geological model, built on the basis of available composite well logs, 2D seismic reflection profiles, isochron maps and top Apula isobaths maps, permit to assess the timing and kinematics of faulting. In fact, by considering both thickness and lithological variations of the Cenozoic sedimentary deposits topping the Mesozoic platform carbonates, not only the age of faulting, but also the fault kinematics. Moreover, the results of fault displacement analysis carried out along the individual segments of a major NW-SE to NNW-SSE oriented fault zone, which crosscuts the whole Eocene-to-Early Pliocene sedimentary succession marking the transition between foredeep and foreland structural domains, are discussed in terms of fault growth mechanisms.

As a result, the geological model shows, along the eastern portion of the study area, a major NW-SE trending, about 50 km-long and 1 km-throw, fault zone which displaces the Eocene-to-Early Pliocene terrenes. The fault zone is interpreted as made up of four individual, SW-dipping, fault segments. The thickness distribution of Cenozoic deposits, computed across the individual fault segments pertaining to the NW-SE fault zone, is consistent with a pronounced dip-slip extensional kinematics, which took place during both Eocene and Early Pliocene times. On the contrary, both structural architecture of the study area and localized thickening of the Upper Miocene terrenes are consistent with pronounced right-lateral components of slip at that time. The 2D throw profiles computed across the individual fault segments point to a switch from single to coherent fault growth mechanisms with time, which likely took place during the Upper Miocene time due to fault linkage. All results are summarized in a conceptual model of fault zone evolution, and discussed taking into account the complex tectonic evolution of the Apulian Platform, which formed the foreland domain of both Dinarides and Apennines fold-and-thrust belts.

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Geological Setting of Madielle-Capraia Massif (Alpi Apuane, Italy)

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Keywords: Shear zone, Fold structure, Marble, Alpi Apuane.

The study area is located in the western part of the Alpi Apuane tectonic window (Northern Apennine, Italy) along a transect from Madielle Massif to Mt. Focoraccia (North of the Massa city), where are extracted precious marbles varieties. The new data acquired through traditional geological survey and by photo-interpretation of high resolution images derived from airborne lidar and optical proximal sensing allowed us to define the structural setting of this area. In the geological literature Madielle and Focoraccia synclines are interpreted as minor structures of Vinca-Forno anticline hinge zone. The Focoraccia syncline flanks are made up of carbonate formations ("Grezzoni" dolomites, Megalodont Marbles, Seravezza Breccias and Marble S.S.) of Norian and Hettangian age, that overlay the Hercynian Basement. Instead, the Madielle syncline flanks consist of carbonate formations ("Grezzoni" dolomites, Megalodont Marbles and Marble S.S.) aged between Norian and Hettangian, and the core is made up of silico-carbonate formations (Zebrino Marble and Cherty Meta-limestones) of Sinemurian - Pliensbachian age.

The tectonic evolution of the Alpi Apuane metamorphic complex is polyphasic and characterized by ductile and brittle deformations connected with the Tertiary evolution of the Apennine orogenic wedge.

In the study area the following elements are particularly evident:

i) the deformation geometries in low-grade metamorphic conditions (green schists facies), produced by the contractional tectonic regime (D1), which led to the structuring of the Madielle and Focoraccia synclines with top-Est facing.

ii) The effects of the retro-deformation (D2), created during ductile regime and low grade metamorphism, probably contemporary to the final stages of the orogenic wedge building, which develops a synform/antiform structure, from kilometric to decimetric in size, with a top-West facing.

iii) The subsequent deformation phase (D3) is characterized by significant shear zones and low angle normal faults connected to the left and right transfer systems which overprint the previous fold systems. In the study area, this tectonic phase, is well developed and transposes almost completely all the previous structure. Important shear zones, with main component top-SW, are responsible for the major tectonic elisions that characterize the flanks of the Madielle syncline. Among the most important shear zones studied, we find one that develops approximately along the Madielle ditch - Banditello peak, where is exposed the overlay of the Hercynian Basament on Mesozic carbonate formations; and another that develops in a NW-SE, direction in the NE side of the Madielle Massif, bringing in direct contact Cherty Meta-limestone with the Grezzoni formation.

This deformation phase was developed in late- to post-metamorphic conditions, and is responsible for complex structural framework that characterizes the study area.

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Carbonate concretions in loose Quaternary sediments as markers of paleo-fluid flow induced by the development of the Quattro Castella Anticline, Northern Apennines, Italy

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Keywords: Diagenetic alterations, carbonate concretions, Quattro Castella anticline.

Diagenetic alterations and mineral masses may provide a useful tool to understand paleo-fluid flows in transforming porous media. In compressive settings of a fold-and-thrust-belt, the presence of deep or blind thrusts could lead to the generation of folds that strongly affects syn-kinematic sedimentation, deep fluids migration and shallow fluid flow pattern. In this contribution we present a multidisciplinary field and laboratory study on carbonate concretions developed in poorly lithified, syn-kinematic sediments of the Quattro Castella anticline in Northern Apennines (Italy) in order to constrain the paleo-fluid flow pattern during the fold growth. The study site is located along the Enza River, where Quaternary shallow marine to continental sediments are exposed. The entire exposed section is a portion of the forelimb of the growing thrust-related anticline, active since Late Miocene times. Field mapping was aimed to link bedding attitude of synkinematic sediments with the geometry, arrangement, shape and size of concretionary bodies. Concretions are both tabular (i.e. parallel to bedding) and elongate single or coalescent concretionary bodies (i.e. plunging parallel to bedding dip). Concretions dimensions range from a few centimeters in single elongate concretions, up to a few meters in tabular and coalescent ones. In situ permeability measurements and laboratory grain size analyses were performed along the studied section to constrain the petrophysical properties of sediments hosting carbonate concretions. Carbon and oxygen stable isotopes analyses, together with petrographic and catodoluminescence observations, were used to better constrain the diagenetic environment in which calcite precipitation occurred. Our results indicate that the growing anticline promoted the development of a local topographic and hydraulic gradient which induced cement precipitation in the form of carbonate concretions in synkinematic sediments. Such diagenetic alterations can be a good marker to reconstruct the paleo-fluid flow history in structurally complex siliciclastic reservoirs.

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Use of analogue models as drivers for 3D fracture pattern predictions in fault-related-folds

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Keywords: sandbox modelling, folding-related fracturing, fracture pattern, computer modelling.

Thrust-related anticlines in the frontal parts of thrust-and-fold belts and accretionary prisms are a well-known play for hydrocarbon exploration. Folding-related fractures provide first-order contributions to determine both secondary porosity and fluid flow pathways. Accordingly, fracture pattern predictions with low uncertainty is a fundamental issue for correct reservoir exploitation. Among the drivers that concur to determine the distribution of fractures in fold-and-thrust-belts, the complex kinematic pathways of folded structures play a key role. Sandbox analogue modelling can provide effective support for developing and validating reliable hypotheses on structural architectures and their evolution, particularly in areas with scarce and not reliable underground information. Given the granular matter that is commonly used to simulate the mechanical behavior of the upper crust, direct predictions of fracture patterns from sandbox analogue models are typically not reliable. However, these models can provide kinematic pathways suitable to be implemented in numerical models to drive fracture pattern predictions. In this contribution, we propose a working method that combines both analogue and numerical modelling. We deformed a sand-silicone multilayer to eventually produce a non-cylindrical thrust-related anticline at the wedge toe, which was our test geological structure at the *reservoir* scale. We cut 60 serial cross-sections through the central part of the deformed model to analyze faults and folds geometry using dedicated software (*3D Move*). Serial cross-sections were also used to reconstruct the 3D geometry of reference surfaces that compose the deformed mechanical stratigraphy thanks to the use of the software *GoCad*. From the 3D model of the experimental anticline, by using *3D Move* it was possible to calculate the cumulative stress and strain underwent by the deformed reference layers at the end of the deformation and also in incremental steps of fold growth. Based on these model outputs it was also possible to predict the orientation of three main fractures sets (joints and conjugate shear fractures) and their occurrence and density on model surfaces. The next step was the upscaling of the fracture network to the entire digital model volume, to create DFNs at *reservoir* scale.

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Structural analysis of Ganymede grooved sulci: insights for a global expansion model

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Keywords: Ganymede icy satellite, Global expansion model, Grooved terrain.

Grooved terrain, consisting of hundreds kilometers long swaths of parallel, periodically-spaced ridges and troughs of different orientation and shape, characterizes the surface of the Ganymede icy satellite. This terrain constitutes tens-to-hundreds kilometers wide sulci of light terrain interposed between dark terrain units and likely results from fragmentation and separation of the dark terrain. Grooved terrains have been often considered as tectonic-related structures within an extensional-dominating regime (*e.g.*, Collins et al., 1998; Pappalardo et al., 1998). Although there is a complete agreement about the primary role of extensional faulting, more debated is the evaluation of the total amount and origin of Ganymede expansion (*e.g.*, Squyres, 1980; Showman et al., 1997; Bland et al., 2009).

Evidence for crustal plates drifting and their relative movements have been constrained, in some key areas of the satellite, by the recognition of piercing points such as craters and/or groove lanes that allowed restoring the terrains to a pre-deformed scenario through the closure of the sulci interposed between the dark plates. This kind of interpretation suggests an extensional deformation mostly guided by Mode I open fractures along regional-scale spreading centers. In the majority of the observed cases, sulci showing "smoother" terrains constitute spreading centers, where total resurfacing is supposed. In other cases, where later or no break-up occurs, grooves may represent fault systems in incipient or aborted rift, respectively, and the resurfacing could be local along some dike-induced fault planes.

A global expansion model could justify large extension and new crust formation along with the absence of contractional features. We suggest that extension through the development of spreading centers may play a primary role in the tectonic evolution of the globally expanded Ganymede, as hypothesized for other icy satellites such as Europa.

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Fractal clustering analysis of vents and fractures: a unified method for fluid source depth investigation

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Keywords: fractures, fractal clustering, mud volcanism, fluid source, icy moons, mars, enceladus, faulting.

The occurrence and distribution of monogenic eruptive features in volcanic areas on Earth has been linked to fracture systems, that allowed hydraulic connection between surface and deep magma reservoirs (Mazzarini et al., 2010; 2013).

The spatial distribution of vents can be studied in terms of self-similar (fractal) clustering, described by a fractal exponent D and defined over a range of lengths (l) between a lower and upper cutoff, Lco and Uco, respectively. The computed Uco values for several volcanic fields on Earth match the thickness of the crust between vents and magma reservoirs at depth.

We applied this method to the Ascraeus Mons volcano on Mars, which presents hundreds of collapse pits similar to those observed on Earth volcanoes, and that are most likely related to feeder dykes. The presence of a large magma reservoir probably related to a plume head and also a shallower magma chamber below the volcanic edifice were inferred. (Pozzobon et al., 2014).

The fractal distribution of putative mud volcanic edifices mapped within several craters in Arabia Terra (Mars) was also investigated. In fact, in this area and its surroundings it is well known the presence of sulfates deposits (Flahaut et al., 2015; Baioni et al., 2013) both related to evaporation, spring (Allen and Oehler 2008; Rossi et al., 2008) and mud volcanic activity (Pondrelli et al., 2011; Komatsu et al., 2015) testifying the presence of liquid water activity in the subsurface. We could thus infer the presence and depth of a likely pressurized fluid level feeding the mud volcanoes.

Since with the fractal clustering method we could gather information about the thickness of a fractured crust, it is possible to apply it to the highly fractured icy satellite's surface, such as Saturn's moon Enceladus. In fact, it is nowadays widely accepted the hypothesis of a presence of a subsurface liquid water ocean below Enceladus' icy crust. This was proved by the presence of water plumes in the south polar terrain and recently verified with gravity data from NASA Cassini mission flybys by Iess et al. (2014). By analyzing fractures self-similar clustering on Enceladus' surface, we could thus support the hypothesis of the presence of a subsurface ocean and estimate its depth below the icy shell.

This analysis can be extended to other volcanic fields and volcanoes on rocky/icy planets in the solar system where features such as vents, dykes and fractures occur, and for where complementary geophysical data are currently lacking.

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Uncoupled vs. coupled thrust belt-foreland deformation: a model for Northern Patagonia inferred from U-Th/He dating

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Keywords: Patagonian Andes Apatite (U-Th)/He dating Foreland deformation.

Despite the general along-strike continuity of the Andean orogen, this mountain belt is characterized by an appreciable internal tectonic segmentation marked by a variable position of the magmatic arc and of the deformation front in the retroarc area at various latitudes. This complex structural architecture makes the Patagonian Andes a unique natural laboratory to study the effects of slab dynamics on near-surface deformation. The present-day building of the southern Andes is interpreted to have been controlled by alternating stages of flat- and steep-slab subduction, which produced shortening and upper plate extension episodes (Folguera & Ramos, 2011; Orts et al., 2015), respectively. Furthermore, the deformation in this whole retroarc sector varied not only in time (i.e. with major 'cycles' of mountain building and orogenic collapse), but also in space, due to the variable transmission of horizontal compressive stress away from the orogen that produced an irregular unroofing pattern.

In this study, we have integrated field structural observations with new apatite (U-Th)/He data (AHe) and published apatite fission-track ages in the Esquel-Gastre area (located at latitudes 41°30'–43°S) in order to analyse and compare the exhumation patterns from the frontal part of the orogen and from the adjacent foreland sector, as well as to gain new insights into the timing and modes of coupling vs. uncoupling of the deformation between the northern Patagonian fold and thrust belt and its foreland. The obtained data indicate a markedly different unroofing pattern between the 'broken foreland' area (characterized by Late Cretaceous to Paleogene exhumation) and the adjacent Andean sector to the west, which is dominated by Miocene-Pliocene exhumation.

Our study supports the idea that the configurations of the slab (flat vs. steep) during subduction can control the coupling vs. uncoupling of the deformation between the thrust belt and the foreland. Along the studied transect, late Miocene to Pliocene AHe ages from the frontal part of the northern Patagonian Andes correlate well with a recent shortening and exhumation stage that took place in the thrust belt during steep-slab subduction and rollback. On the other hand, AHe ages obtained for the 'broken foreland' unravelled exhumation at near-surface conditions during Late Cretaceous to Paleogene times, when a phase of flat-slab subduction favoured the coupling between the thrust belt and the foreland area and associated widespread shortening over the whole South American continent at the studied latitudes.

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Cyclic contractional and extensional deformation pulses recorded along the fault system bounding the Montagna dei Fiori Anticline to the West, Central Apennines, Italy

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Keywords: Structural inversion, Montagna dei Fiori Anticline, structural inheritance.

The Montagna dei Fiori Anticline, at the mountain front of the Central Apennines (central Italy), provides a well-known example of syn-rift tectono-sedimentary inheritance preserved in a thrust-related fold, and affected by tectonic inversion. Several studies described the pattern of syn-rift Jurassic faults that were then affected by positive inversion. Alternative interpretations have been proposed, such as a dominant role of late-thrusting extensional faulting, or a negligible role of tectonic faulting in favour of gravity-driven olistoliths. To obtain further constraints on the deformation history of the Montagna dei Fiori Anticline and its relationships with dolomitization, we performed a multidisciplinary study of the tectono-sedimentary pattern and paleofluid history in the Jurassic and Lower Cretaceous carbonates exposed in the anticline. Detailed mapping of the central part of the anticline, bed-perpendicular logging of syn-rift and post-rift strata, structural, petrographical, geochemical, microthermometrical, and petrophysical analyses were used to reconstruct the evolution of this anticline, starting from the pre-orogenic architecture up to its subsequent orogenic reworking. These data reveal: (1) the pre-orogenic tectono-sedimentary architecture of a folded Jurassic fault network; (2) multiple superimposition of extensional and contractional episodes of deformation on the same fault zones; (3) the presence of at least one main dolomitization episode, the timing of which is still being deciphered; (4) demonstrate the causal link between faulting and dolomitization, which favoured formation of dolostones along fault zones, particularly in the intersection/abutting areas between E-W and N-fault trends. These new data allow us to definitively discard the hypothesis that lower Jurassic platform carbonates in the Apennines formed due to gravity-driven olistoliths. In contrast, our results support a model whereby these platform carbonates formed as syn-rift extensional fault-bounded blocks. We propose that alternating contractional and extensional deformation events recorded on the main fault zones exposed in the Montagna dei Fiori Anticline results from the interplay between thrust sheet imbrication and antiformal stacking at depth, and episodic gravitational instability near the surface, which caused negative inversion of inherited fault patterns. Since the stratigraphic units and deformation histories at Montagna dei Fiori exist in folds elsewhere in the Central Apennines, these findings impact the regional interpretation of controls on the formation of dolostone geobodies. Ultimately, our work reconfirms the fundamental role of structural inheritance on younger structural patterns and the importance of that inheritance to drive fluid flow and associated diagenetic alteration.

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A multi-scale approach for understanding the role of hydrocarbons content on the mechanical properties of rocks: insights and implications for the Majella reservoir (Italy)

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Keywords: Majella Reservoir, multi-scale data, petroleum, mechanical properties.

Crustal processes such as deformations or faulting are strictly related to the petrophysical properties of involved rocks. These properties depend on mineral composition, fabric, pores and any secondary features such as cracks or infilling material that may have been introduced during the whole diagenetic and tectonic history of the rock. In this work we investigate the role of hydrocarbons (HC) in changing the petrophysical properties of rock by merging multi-scale data focusing on the carbonate-bearing Majella reservoir (Bolognano formation). This reservoir represent an interesting analogue for the several oil fields discovered in the subsurface in the region, allowing a comparison of a wide range of geological and geophysical data at different scale. The investigated lithology is made of high porosity ramp calcarenites, structurally slightly affected by a superimposed fracture system and displaced by few major normal faults, with some minor strike-slip movements.

Within this lithology two groups were investigated: 1. clean rocks (without oil) and 2. HC bearing rocks (with different saturations). For both groups, density, porosity, P and S wave velocity, and elastic moduli measurements at increasing confining pressure were conducted on cylindrical specimens at the HP-HT Laboratory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome, Italy.

For clean samples at ambient pressure, laboratory porosity varies from 8 % up to 28 % and P wave velocity (Vp) spans from 4,1 km/s to 4,9 km/s and a very good correlation between Vp, Vs and porosity is observed. The P wave velocity at 100 MPa of confining pressure, ranges between 4,5 km/s and 5,2 km/s with a pressure independent Vp/Vs ratio of about 1,9. The presence of HC within the samples increases both Vp and Vs. P-wave velocity hysteresis measured at ambient pressure after 100 MPa of applied confining pressure, suggests an almost perfectly elastic behaviour for oil-bearing samples and more inelastic behaviour for cleaner samples. These data are confirmed by cyclic deformation test where HC-bearing samples generally record higher strength, higher Young's modulus and smaller permanent strain.

In order to compare our laboratory results at larger scale we selected 11 outcrops of the same lithofacies of our samples both clean and HC-bearing. Preliminary results on fractures orientation, from the scan-line method, are in general agreement with literature data strengthening our observations. Spacing data show higher fracture frequency for clean outcrops respect to HC-bearing outcrops confirming laboratory observations.

In conclusion, laboratory experiments highlight a more elastic behaviour for HC-bearing samples and HC-bearing outcrops are less fractured respect to clean outcrops. We then infer that HC presence preserved the HC bearing portions from fracturation predating HC migration respect to the last stage of deformation of the Bolognano formation.

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3D Structural Model of the Po Valley basin (Northern Italy): results, conclusions and perspectives

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Keywords: 3D models, structural geology, seismo-tectonics, foreland basins, Po Valley, northern Italy.

The performed 3D structural model of the Po Valley basin leads from the basic geological framework to the deformation geometries and kinematics across the region, to some of the possible model applications and future perspectives.

The model has been created by the integration of public depth-data and the progressive sculpting of the performed 3D units, tied to the available cross-sections, maps, outcrops and wells.

Despite the possible simplification and the associated uncertainty, mainly due to quality and distribution of the initial dataset, the Po Valley model is consistent with the structural setting and the kinematics of the basin from crustal to field scale, with proved applications to reviewing of the basin structure-earthquake associations and thermal modeling of the potential hydrocarbons from the Mesozoic systems.

Key results from the model are the following:

1. The Po Valley crustal architecture and structures at any model layer are controlled by the Moho geometry;
2. The foreland basin is defined by two major structural domains (eastern and western of the NNE-SSW oriented Giudicarie trend), where sediment distribution/thickness and structural style are substantially different;
3. The modeled Tertiary foredeep basin geometry/migration are strongly controlled by the foreland pre-Alpine tectonics;
4. The influence of the inherited extensional structures on the compressional structure evolution is clear until Miocene time, when the foreland show double-flexure towards the north and the south, below the Southern Alps and Northern Apennines advancing chains, respectively;
5. During Pliocene, flexure of the Adria/Po Valley foreland is essentially south-verging below the Apennines: at this stage, the influence of the Mesozoic fabric is subtle and deformation across the foreland is essentially controlled by subduction of the Po Valley lithosphere below the Apenninic belt;
6. Seismicity across the region is mainly related to a) the Northern Apennines buried fronts, b) the eastern sector of the Southern Alps-Po Valley boundary zone, c) some facies transition in the Mesozoic platform-to-basin carbonates;
7. The final thermal modeling built on the 3D structural model is capable to

- confirm the hydrocarbon generation history suggested by previous authors,
- compare the model results with hydrocarbon production from the major oil fields in the region,
- correlate hydrocarbon generation, migration and accumulation with trap formation across the basin,
- suggest the presence of fluid overpressures as a potential key factor in delaying the hydrocarbon maturation inside the deep Mesozoic carbonates of the western Po valley.

The current model is to be intended as the base-case 3D scenario for future applications in the various domains of the earth science, namely education, hydrocarbon exploration, hydrogeology, CO_2-CH_4 storage and geo-archeology.

The model, built and analyzed by a combination of different software (MOVE, Kingdom, Structural Solver, GOCAD) is a redy-to-use product which, in order to reduce uncertainty while increasing the predictive potential, is expected to be locally refined and implemented through addition of further data.

Whether correct or not, the Po valley 3D model building resulted in a number of lessons learned that possibly represent the real achievements of the study thanks to their applicability elsewhere and worldwide.

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Deconvoluting complex structural histories archived in brittle fault zones

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Keywords: fault zones, seismogenesis, strain localisation/partitioning.

Faulting accommodates momentous deformation and its style reflects the complex interplay of often transient processes such as friction, fluid flow and rheological changes within generally dilatant systems. Brittle faults are thus unique archives of the stress state and the physical and chemical conditions at the time of both initial strain localization and subsequent slip(s) during structural reactivation. Opening those archives, however, may be challenging due to the commonly convoluted (if not even chaotic) nature of brittle fault architectures and fault rocks. This is because, once formed, faults are extremely sensitive to variations in stress field and environmental conditions and are prone to readily slip in a variety of conditions, also in regions affected by only weak, far-field stresses. The detailed, multi-scalar structural analysis of faults and of fault rocks has to be the starting point for any study aiming at reconstructing the complex framework of brittle deformation. However, considering that present-day exposures of faults only represent the end result of the faults' often protracted and heterogeneous histories, the obtained structural and mechanical results have to be integrated over the life span of the studied fault system. Dating of synkinenatic illite/muscovite to constrain the time-integrated evolution of faults is therefore the natural addition to detailed structural studies. By means of selected studies it will be demonstrated how careful structural analysis integrated with illite characterization and K-Ar dating allows the high-resolution reconstruction of brittle deformation histories and, in turn, multiple constraints to be placed on strain localization, deformation mechanisms, fluid flow and mineral authigenesis within actively deforming brittle fault rocks. Multi grain-size illite dating permits the investigation in time coordinates of the subtle details of initial localization and subsequent reactivation(s). This innovative approach makes it possible to refine the understanding of fundamental geological processes such as seismogenesis and strain localisation/partitioning and helps us move towards time-constrained structural models, where illite characterization and K-Ar analysis are rapidly becoming a viable tool to date faulting and alteration in rocks.

Session S3

Multi-methodological approaches in the characterization of fractures and fault zones

Conveners and Chairpersons

Giovanni Florio (Università di Napoli Federico II)
Alfredo Mazzotti (Università di Pisa)
Adele Manzella (CNR-IGG Pisa)
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Using well log data and statistical Gaussian simulations to estimate the crack density value within a geothermal reservoir located in fractured hard rocks

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Keywords: Fractured Hard Rocks, Geothermal explorations, Crack density, Statistical Simulations.

To identify the most promising targets when exploring fractured geothermal reservoirs it is crucial to infer the crack density value (the fracture density per volume) in the subsurface. In this work we use statistical simulations to estimate the crack density value within fractured portions of the Larderello–Travale area where deep intrusive/metamorphic rocks constitute the main drilling targets of geothermal exploration. Waveform sonic recording and circumferential borehole imager log acquired in the investigated area, evidence the presence of several vertically aligned fractures with a preferential orientation NNW-SSE at the depth of the productive levels, whereas the encasing rocks appear to be quite isotropic. This characteristic allows us to approximate the target level as a transverse isotropic medium with a horizontal axis of symmetry (HTI medium). Then, basing on the well data and by using a statistical technique, we develop several models that keep the encasing medium and the strike of the fractures within the target constant, but change the crack density from 0 (no fractures) to 0.1 (highly fractured).

More specifically, in our approach the statistical characteristics (covariance matrix, and autocorrelations) derived on velocity logs in the tight rock are supposed to be stationary and equal to those in the fractured interval. These statistical properties will serve us to generate mutually and vertically coupled velocities within the target interval in the following statistical simulation. The average P-wave, S-wave velocity and density values computed from the logs in the tight encasing rock are used to derive the average Lamé parameters of the isotropic rock. Then, by assuming a given value for the crack density in the target, fractured, level we compute the associated elasticity tensor following Aleardi et al. (2015). This elasticity tensor is used to derive the average Thomsen anisotropic parameters and the average P-wave and S-wave velocities for the simulated HTI fractured zone. Finally, these average velocities values, together with the autocorrelation and the covariance matrix previously computed are used to perform a statistical simulation, in which, by assuming Gaussian distributed properties we generate vertically and mutually correlated P-wave, S-wave velocities for the fractured zone for each given crack density value. After each simulation the match between the simulated P-wave and S-wave velocities with the actual logs in the fractured interval is used to determine the most likely crack density. The proposed methodology applied to different wells returns plausible results for the crack density value and together with reflection seismic observations may bring to predict fracture orientation and density.

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GPR response to fractures with different filling materials

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Keywords: GPR, rock fractures, thin-bed, thickness, filling material.

Rock masses are generally affected by the presence of fracture networks whose geometrical, mechanical and morphological features control the behavior of the rock mass in terms of permeability, deformability and overall stability. Rockfalls, rockslides, deep-seated gravitational slope deformations as well as collapses of underground tunnels and shafts are most often caused by fracture networks (Longoni et al., 2012). Geometrical parameters of the discontinuities as dip, dip direction and spacing are generally measured by means of classical geological mapping performed at the rock surface. Morphological parameters as aperture, filling material, roughness and persistence can also be measured at the rock surface, but they can significantly vary inside the rock mass.

In this work we employ the Ground Penetrating Radar (GPR), a high frequency electromagnetic device, to investigate rock fractures in a non-destructive manner. More in details we focus on laboratory experiments carried out to assess the capability of the GPR system to estimate the thickness and the filling material of rock fractures. Lab specimens consist of a wafer of Carrara marble blocks (75x60x21cm) and different materials, namely air, Kaolinite and high-density polyethylene (HDPE) sheets that are used to simulate the presence of a fracture with known filling. Shielded antennas with a nominal frequency of 1 GHz, 2 GHz and 3 GHz were employed and data were collected in time-triggering mode by placing them in the middle of the top block and varying the fracture thickness.

Processing of GPR datasets rests on the assumption that fractures can be generally envisaged as thin beds embedded in a homogenous rock formation, this yielding a complex reflection pattern caused by the reverberation of the GPR signal back and forth within the bed. After a basic pre-processing sequence consisting of trace windowing, wide-band zero-phase low pass filtering, amplitude and jitter correction with respect to a reference trace and pre-whitening, thin-bed response is recovered by means of deterministic deconvolution. Results obtained so far demonstrates that whenever the materials that might fill the fracture are well known (e.g., air, water and clay) the proposed approach can accurately estimate the thin bed thickness and can discriminate the filling. On the contrary, when no a priori assumptions on the filling are available, the approach can only provide a rough discrimination between dry or saturated filling and, although the normalized thickness is accurately estimated, the real thickness is poorly determined.

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Oceanic Megatransforms: A New Type of Plate Boundary

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Keywords: Transform faults, Oceanic plate boundaries.

The introduction by Wilson (1965) of the concept of transform fault was a key step in the development of the theory of Plate Tectonics. Transform faults offset the axis of mid-ocean ridges, and are the locus of strike-slip motion at the boundary of two plates that slide past each other. Oceanic transform boundaries are manifested by narrow (a few km) highly seismic strike-slip fault zones joining the two offset ridge segments. This is in contrast with continental transform systems, such as the St. Andrea or the N. Anatolian faults, that display broad (>100 km) and complex areas of deformation.

The idea of simple, narrow oceanic transform faults has found at least two exceptions. One is the Romanche transform, that offsets the equatorial Mid-Atlantic Ridge by over 900 km, displaying a lens-shaped, >120 wide complex zone of deformation between the two ridge axes (Bonatti et al., 1993). The other is the Andrew Bain transform, that offsets the South West Indian Ridge (SWIR) by about 750 km, also shows a wide (about 100 km) lens shaped zone of deformation (Sclater et al, 2005).

We describe the peculiar features of these transforms and we propose call them as “Megratransforms”. The St. Paul transform (equatorial Atlantic) functioned probably as a megatransform up to about 50 Ma. St. Paul subsequently split in four segments separated by short spreading centers (Hekinian et al., 2000). Oceanic megatransforms constitute a new type of plate boundary: modeling described in Ligi et al. (2002) suggest that megatransforms can form when the age offset is > 30 million years. The broad deformation zones could be considered as semistationary microplates.

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Results of high-resolution seismic reflection profiling across Paganica-S. Demetrio Fault, in the epicentral area of the 2009, Mw 6.3 Aquila (Italy) earthquake

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Keywords: Seismic Reflection, Pre-stack Depth Migration, Common Reflection Surface Stack, Aquila Earthquake

We present for the first time the results of high-resolution seismic reflection profiling across Bazzano and Paganica Basin and across the shallow segments of the Paganica-S. Demetrio Fault, which has been indicated as the causative fault of the 6th April 2009 (Mw 6.3) earthquake. The seismic data were collected along four dense wide-aperture profiles, that run SW-NE for a total length of ~6 km, mostly in the hanging wall of the Paganica-S. Demetrio Fault.

To evaluate the optimal seismic imaging strategy, we applied three different processing techniques to the dense, wide-aperture acquired data: a conventional CMP reflection processing; pre-stack depth migration (PSDM); and finally the Common-Reflection-Surface (CRS) stack technique, PSDM has proven capable of overcoming many of the typical drawbacks of CMP processing in presence of complex velocity distributions. However, PSDM is highly sensitive to the accuracy of the background velocity model, which we were able to estimate for Bazzano but not for Paganica profile, due to both higher structural complexity and higher level of ambient noise. In these settings the data-driven and velocity-independent CRS method provided a feasible alternative for seismic imaging in Paganica sub-basin.

The seismic images of Paganica and Bazzano basins resulting from our high-resolution survey shows a rather complex tectonic framework. Paganica basin is about 100 m shallower than Bazzano, which reaches about 450m deep and is clearly asymmetrical. Overall we image a large number of small to large offset faults with a NE and SW dips and offsetting both young sediments ant the Meso-Cenozoic Basement. Along Bazzano basin NE dipping faults show the higher vertical offsets. Some of these faults are spatially correlated with topographic flexures across the seismic profile and with the surface ruptures that occurred during the 2009 earthquake.

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Temporal variations in the nucleation zone of the 2009 L'Aquila earthquake through a joint analysis of fault-zone trapped waves and stress release

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Keywords: Source parameters, Brune stress drop, apparent stress drop, Savage-Wood radiation efficiency.

A reconstruction of spatial and temporal processes governing the preparatory phase of the M_w 6.1 L'Aquila main shock is made using repeating earthquakes occurred in the nucleation zone. Many of these shocks were generated within or near the damage fault zone: waves propagating along the fault, the so-called fault-zone trapped waves (FZTW), contain important information on fault processes. The analysis of these waves revealed a sudden jump of their spectral amplitudes 7 days before the main shock, after the occurrence of the M_w 4.1, 30 March 2009 largest foreshock. The amplitude increase was accompanied by a loss of waveform coherence. The concomitance of a consistent change in amplitude of FZTWs with the loss of coherence led us to interpret our observation as due to a sudden temporal variation of the velocity contrast between the fault damage zone and the hosting rocks in the focal volume, depending on physical processes occurring in the preparatory phase. FZTWs are thus a useful tool to track temporal changes occurring near the rupture nucleation of the L'Aquila mainshock, with the clear indication of a strong decrease of shear-velocity in 1 day. This temporal variation coincides in time with signatures of changes in other seismic parameters such as the b value, the spatio-temporal distribution of the events, the P-to-S wave velocity observed by several authors.

Another important inference on the geometry of the deep structure of the L'Aquila fault has been obtained modelling the FZTWs recorded by two clusters located at the northwestern and southeastern tips of the fault plane of the main shock rupture. The Paganica Fault and the San Demetrio Fault, mapped as disjoint segments, are part of a longer and continuous fault system continuous at depth.

The waveforms of the repeating earthquakes are also used for a stress release analysis. Although estimates of Brune stress drop and apparent stress can suffer huge uncertainties, the use of the same analysis procedure on repeating earthquake reduces significantly the estimate fluctuations. The Savage-Wood radiation efficiency obtained through the ratio between the apparent stress and the Brune stress drop shows that the 30 March largest foreshock is characterized by a very high Savage-Wood radiation efficiency value**.** A temporal anomaly is observed for this parameter as well. This evidence adds further information on the seismic source dynamics and the physical properties of the seismogenic region.

High-resolution geometry of Castellaccio Pluton by Electrical Resistivity Tomography (ERT)

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Keywords: Corsica-Sardinia Batholith, Geophysical Exploration, Variscan Belt, Asinara Island.

The geometry of granitic plutons is usually investigated by integrating field structural data and deepest geophysical exploration methods, such as gravimetric and seismic modeling. Electrical Resistivity Tomography (ERT) has been rarely used due to its limited depth of application, though generally it provides high-resolution results. In this contribution, we explore the applicability of these ERT methods to reconstruct the geometry of the contacts in the Castellaccio Pluton, a Variscan composite granodioritic intrusion exposed at the Asinara Island (northern Sardinia, Italy). Field-structural mapping shows that the pluton consists of three compositionally and texturally distinct units. Structural markers such as phenocrysts, metamorphic xenoliths and mafic enclaves were utilized in order to reconstruct the magmatic flow trajectories. Field data and geological-structural analyses were integrated with ERT profiles, acquired using a multi-electrode system (Dahlin, 1996). The device consists of an Abem Terrameter SAS1000 combined with an electrode selector ES 10-64 (ABEM Instrument AB, Sweden). The Wenner-Schlumberger array configuration (n = 2) was used for data acquisition.

The high resistivity contrast between the granite (600-2000 $\Omega \cdot m$) and the metamorphic basement (200-600 $\Omega \cdot m$), allowed the ERT method to reconstruct the Pluton's with accuracy and the offset of post-magmatic faults.

A multidisciplinary research infrastructure watching the chemico-physical processes governing active faults and the genesis of earthquakes: the Altotiberina Near Fault Observatory (TABOO) case study

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Keywords: Near Fault Observatory active faults earthquakes.

Crustal faults are complex natural systems whose mechanical properties evolve with time. Thus, the understanding of the multi-scale physical-chemical processes responsible for earthquakes and faulting requires considering phenomena at the boundaries between different research fields and the availability of long time series of high-resolution data. That is why for the past ten years there has been a worldwide commitment to identify Natural Laboratories (NL) where installing state of the art observational systems. There are three main requirements for the NL: must have a reasonably small extension, there must be active faults on it and it must have a regular occurrence of earthquakes.

We present the Altotiberina Near Fault Observatory (TABOO), a research infrastructure devoted to studying slow and fast deformation processes acting along a normal fault system located in the upper Tiber Valley (northern Apennines), dominated by a 60 km long low-angle normal fault (Altotiberina, ATF). TABOO consists of about 50 permanent seismic, geodetic and geochemical stations covering an area of 120×120 km^2.

Basing on a set of semi-automatic modular procedures producing high-resolution information, we present TABOO primary results regarding the fault system anatomy and the active role played by the Altotiberina fault in accommodating the on going tectonic extension in this sector of the chain.

In addition to this we will describe how we intend to enhance the NL to create a multi-sensor network able to broaden the range of monitored parameters potentially related to the earthquake preparatory with the ambitious challenge of describing and modelling the processes controlling the faulting phenomena and seismicity evolution at the scale of the single fault segment.

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Synthetic seismic reflection modelling of shallow and deep structures of the Larderello geothermal system

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Keywords: Larderello geothermal filed, 3D geological-geophysical model, seismic modelling.

Exploration strategies of geothermal reservoirs may significantly benefit from the development of synthetic seismic reflection profiles by confirming the possibility to detect prospective features on acquired seismic reflection data and to calibrate geological-geophysical interpretation and model reconstructions. To be elaborated a synthetic seismic reflection profile requires a conceptual geological model of the subsurface structure and physical properties.

The Larderello geothermal field is characterized by a shallow reservoir and a deep one. The latter is hosted in the metamorphic basement (Batini et al., 2003; Bertini et al., 1996). In seismic reflection profiles the deeper reservoir is characterized by a strong amplitude reflective signal, the well known K-horizon, widely observed in several seismic lines (Batini et al., 1978, Accaino et al., 2005) and probably drilled by the San Pompeo 2 well (Gianelli et al., 1997).

In this study, the geological and geophysical available data, for the portion of the Larderello geothermal field drilled by the San Pompeo 2 well, have been integrated to develop a new 3D geological-geophysical model. The geological-geophysical model was calibrated with a synthetic seismic modelling of the main seismic units up to the k-horizon along the CROP-18A seismic reflection line.

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Active tectonics along the Trecastagni-San Gregorio-Acitrezza fault system: southern boundary of Mt Etna unstable sector

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Keywords: Geodesy, volcano-tectonics, structural geology.

In the last decades, several studies have clearly detected the seaward motion of the eastern flank of Mt. Etna volcano which is characterized by a network of active tectonic lineaments controlling its morphology and its kinematics. The comprehension of the tectonic processes affecting this unstable sector requires multidisciplinary investigations including: (i) relation between active deformation and surface processes through the integration of geomorphological – paleoseismological methods and high precision geodetic surveying (e.g., GPS measurements, InSAR interferograms); (ii) accurate characterization of the geometry and internal arrangement of seismogenic structures at depth by seismological and applied geophysics surveys by means of environmental noice samplings; (iii) investigation of the mechanical behavior of rocks under variable stress conditions; (iv) modelling of earthquake ruptures, fault dynamic stress fields and ground motion (e.g., peak acceleration) at the surface.

In order to characterize the main features of the unstable flank of Mt. Etna, we performed a detailed study of the surface deformation along the Trecastagni-San Gregorio-Acitrezza fault system. Such a fault system is considered as the main southern boundary of the sliding flank and is constituted of a ~7 km long fault zone roughly E–W oriented and characterized by different kinematics (strike-slip, dip-slip and oblique) and different style of strain release (seismic and aseismic deformation). The fault traces are usually marked by active deformation stripes that are highlighted by the damages caused to buildings and infrastructures. To adequately survey this fault system and provide complementary information on the dynamic of the main fault segments, a local geodetic network has been recently established across the active deformation stripes of the fault system. This network consist of XXX benchmarks and has been measured with both GPS and EDM techniques at least three times since late 2014. In addition, to sample with high detail the active deformation stripes of the fault system, the observed ground deformation pattern has been integrated with available InSAR measurements. These extensive datasets has been used to constrain the kinematics of the fault system using a non-uniform slip distribution model inversion.

Main findings evidence a good correlation with geological field observations highlighting as the active deformation stripes is mainly affected by a right lateral displacement coupled with secondary vertical motions. These findings point out the key role played by the Trecastagni-San Gregorio-Acitrezza fault system in the kinematics and seaward motion of the unstable eastern flank of Mt. Etna, and provides new hints to better constrain its timing and kinematics.

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Multi-scale velocity structure of a seismogenic normal fault zone

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Keywords: seismogenic normal fault zone, petrophysical characterization, Campo Imperatore, Central Apennine

The petrophysical characterization of fault zones (e.g., ultrasonic velocities, porosity and fracture intensity of the fault rocks) is a relevant topic in reservoir geology (exploration and exploitation) and fault mechanics (in terms of both long-term quasi-static and fast dynamic evolution). Here we characterized the shallow subsurface velocity structure of the active Campo Imperatore normal fault zone (Central Apennines, Italy). Based on a detailed structural mapping of the fault zone footwall block performed in the recent years four main structural units separated by principal fault strands were recognized: (i) cataclastic unit, (ii) breccia unit, (iii) high-strain damage zone, (iv) low-strain damage zone. The single units were systematically sampled along a transect (~ 200 m) orthogonal to the average strike of the fault and characterized in the laboratory in terms of petrophysical properties (i.e., Vp, Vs and He-porosity). The cataclastic and breccia units (Vp = 4.7±0.43 ms-1, Vs = 2.7±0.24 ms-1) were significantly “slower” compared to the damage zone units (Vp = 5.6±0.53 ms-1, Vs = 3.2±0.29 ms-1). A general negative correlation between ultrasonic velocity and porosity values was reported; moreover measured acoustic anisotropies seemed to be related to deformation fabrics observed at the sample scale. Vp-Vs seismic refraction tomography was performed in the field along a parallel profile (~ 90 m) across the fault zone. The tomographic results clearly illuminated fault-bounded rock bodies characterized by different velocities (i.e., elastic properties) and geometries which match with the ones deduced from the structural analysis of the fault zone exposures. Facture intensity measurements (both at the sample and outcrop scale) are currently underway to investigate the scaling relation between laboratory and field measurements. These results will be coupled with the ultrasonic velocity vs. confining pressure profiles already measured in the laboratory to extrapolate the subsurface velocity structure of the fault zone to larger depths. In the long term these results will be integrated in both static and dynamic fault mechanics models.

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Travertine deposition and faulting in the geothermal field of Viterbo (Northern Latium/Tuscia, Italy)

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Keywords: Travertine buildups, neotectonics, Viterbo, geothermal springs, fissure ridge, mounds.

Numerous geothermal springs are clustered west of Viterbo in a delimited area of the large volcanic plateau produced between 1,35 Ma e 90 ka, by the emplacement of pyroclastic deposits from three volcanic districts (Cimino, Vico and Volsini). This area corresponds to a buried structural high, interpreted mainly on geophysical data as a complex horst that was previously involved in thrust folds and later affected by the Plio-Quaternary extensional tectonics. The geothermal springs occur along the main structural discontinuity produced by polyphasic tectonics (extensional and/or transtensional) and by the subsequent volcano-tectonic activity. Field work and the results of structural, geomorphological and facies analyses, as well as the interpretation of geophysical and drilling data, were managed in a GIS model with the aim of defining the features of the mesoscopic to map-scale faults. Presently most of the springs deliver sulphate hyperalkaline-earthy waters, that locally precipitate at rates that only exceptionally are greater than 70 cm/year. They overlie or sometimes alternate with the pyroclastic deposits which in turn rest on the Pliocene marine clays and sands of the Tiber Valley graben or locally the pre-orogenic sedimentary substratum, exposed on the western sector of the area (M. Razzano and Ferento areas). The emplacement of pyroclastic deposits produced a rather flat morphology thus the distal, thermal drainage system developed at the end of the volcanic activity, was characterized by flat carbonate bodies made of microbial laminites dominant on crystalline facies, typical of wetlands/palustrine flats and/or shallow lakes filled with mixed ambient and thermal waters.

The architecture of travertine deposits in the geothermal system of Viterbo can be connected to fossil-to-active tectonics and interpreted as co-seismic or morphotectonic indicator.

Auto built travertine bodies locally develop around the spring vent forming mounds with positive relief such as: fissure ridge, precipitated along major active extensional faults (Bacucco; Aereoporto); shield/crater mushroom-like dome, precipitated at the surface projection of the intersection point of crossing faults (Paliano); punctual venting shield/crater mounds (Piscine Carletti; Bulicame; Bagnaccio) likely to be related to the soft lithology of the deeper substratum.

The results of facies analyses of the travertine bodies suggest that the architecture of the thermal carbonates is controlled by a combined action of different leading processes: active faulting; gravitational collapse and subsidence; fluctuations of gas discharge; all processes symptomatic of neotectonic activity.

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Assessing site effects in faulted rock mass by combining geological and geophysical analyses: the case history of Guarcino (Central Italy)

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Keywords: site effects, local seismic response, topographic effects, faulted rock masses, seismic measureme

Studying seismic response at rock sites characterized by complex geological setting is a challenging issue due the simultaneously occurrence of site effects related to the local morphology (i.e. topography, LeBrun et al., 1999) and widespread faulting/fracturing characteristics of rock masses that constitute the reliefs (Rovelli et al., 2002; Martino et al., 2006; Pagliaroli et al., 2011, 2015).

This paper presents the results of site effects investigation at the village of Guarcino (Central Italy) located on top of a carbonate ridge constituted by Cretaceous limestones that experienced polyphasic tectonic activity prior, during and after the Apennines building (Centamore et al., 2002). We performed (i) geological-structural surveys, (ii) geophysical measurements (i.e., 2D-arrays, MASW, noise measurements processed with HVSR and SSR technique), (iii) geomechanical analyses by using the Schmidt hammer along and across a 50 m-thick fault zone cutting through the Cretaceous limestones.

We reconstructed the architecture of the fault zone, by individuating different structural domains in the rock mass and then we evaluated the fracture intensity across the fault zone by correlating different structural-geometrical parameters (such as discontinuity spacing, discontinuity pervasivity, size of lithons, hardness index as provided by the Schmidt hammer).

Our preliminary results highlights the variability of seismic waves polarization and amplification within the different fault domains, making possible to recognize probable bidimensional and tridimensional site effects.

This work has implication for local seismic response and microzonation studies of urban areas located on rocky landforms, which are widespread in Italy and the Mediterranean region.

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Mapping the seismic expression of fault and their surrounding deformation zones in 3D seismic volumes

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Keywords: Fault zones, damage zones, seismic intepretation, image processing, mapping uncertainty.

Conventional interpretation workflows pick faults from offset stratal reflectors on seismic data to create discrete, sub-planar surfaces. While this approach certainly tracks the discontinuity and highlight the main fault relative displacement, it overlooks any deformation structures surrounding the simple edge discontinuity. Signal disturbance can also be found in 3D seismic volumes that are related to folds. In these cases the volumes of signal disturbance, while characterized by chaotic and discontinuous reflector geometry, retain some amplitude and phase properties. We term these *Seismic Disturbance Zones (SDZs)* and they may have several distinct explanations: inappropriate illumination during the acquisition; the incorporation of diffractive components during the stacking procedure; and an inappropriately-simplified velocity model within the deformed area. All will contribute to the blurring of the signal by down-grading the signal/noise ratio in faulted, damaged and folded volumes. These *SDZs* are commonly characterized by complex perturbations of the signal and occur at the sub-seismic (10s m) to seismic scale (100s m). They may store important information on deformation distributed around those larger scale structures that may be readily interpreted in conventional amplitude displays of seismic data. The lower physical limit of any interpretation is constrained by the ray tracing assumption, which is defined by the vertical tuning thickness (frequency), that is approximately one quarter of the seismic wavelength and laterally by the dimensions of the Fresnel zone that, for depth-migrated seismic, is of the order of the wavelength. So there is a scale, between the Rayleigh limit and the distinctive seismic response, where signal expression is strongly disturbed but can still be interpreted. Our challenge is to use information from SDZs to enhance interpretations of distributed deformation around faults. We introduce a method chiefly using seismic attributes (Chopra and Marfurt, 2005; Gao, 2003; Iacopini and Butler 2011) to detect fault-related disturbance zones and to discriminate between this and other noise sources such as those associated with the seismic acquisition (footprint noise). Two case studies from the Taranaki basin and deep-water Niger delta are presented. These resolve *SDZs* using tensor and semblance attributes along with conventional seismic mapping. We propose a workflow to map and cross-plot seismic waveform signal properties extracted from the seismic disturbance zone as a tool to investigate the seismic signature and explore seismic facies of a *SDZ*.

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A deterministic velocity model to correlate earthquake locations and geological structures: a case study of the Altotiberina fault system

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Keywords: Earthquake locations, Altotiberina fault system.

A key point of earthquake location accuracy and its correlation with the subsurface geology is down to the definition of a reliable velocity model of the subsurface where seismic waves propagate. In approaches where earthquakes are located in seismological models, the correlation between the seismicity distribution and specific lithostratigraphic bodies is analyzed "a posteriori" as part of a qualitative interpretation process. Following a different approach, we construct a deterministic velocity model merging robust geological and geophysical data that allows us to directly correlating earthquake locations computed in such a model with the known geological structures. We present the AT seismic model, a three-dimensional (3D) velocity model for the Upper Tiber Valley region (Northern Apennines, Italy) obtained by integrating 300 km seismic reflection profiles, 6 deep boreholes (down to 5 km depth), detailed geological surveys data and direct measurements of P- and S-wave velocities performed in situ and laboratory. Once tested the robustness of the AT model, we have located about 11,000 earthquakes, recorded by the INGV seismic network from April 2010 to December 2013. Our results image a new picture of the seismicity along the Altotiberina fault system, showing a high degree of spatial correlation with specific lithostratigraphic units and suggesting a possible lithological control on the seismic activity evolution.

Inversion of gravity data across faults: some strategies to obtain density models displaying sharp variations

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Keywords: Gravity anomalies, Constrained inversion, Fault zones.

Gravity inversion is often implemented by minimization of an objective function promoting structural smoothness in each spatial direction, while fitting the observed geophysical response (e.g., Li and Oldenburg, 1998). The output is a model where the density values are smoothly varying across the source volume, but often not clearly representing the available geologic information. For example, in correspondence of a fault zone, sharp boundaries across distinct geologic units are usually imaged as blurred features. Another bad consequence of the smooth nature of the inverted models is that the estimated density values have reduced contrasts with respect to the true values, implying difficulties in their geologic interpretation. Thus, the smooth models obtained through inversion may bear little resemblance to the true geology. Sometimes geophysical inversion and geology differentiation are treated as two independent procedures applied in cascade, but this simple procedure may lead to models that does not adequately fit the observed field. Recently, different approaches were proposed aimed at obtaining inverted models where the physical property distribution is more 'blocky', and so able to give a more accurate representation of the true geology, while still producing a field very similar to the observed one (Sun and Li, 2015; Phillips and Simpson, 2015). We compare different strategies to obtain, in a semi-automatic way, inverted models displaying clear geological boundaries. We test three different approaches, two of which involving the sharpening of the boundaries of the model by using different terracing filters. A third approach exploits the more versatile fuzzy C-means clustering (Bezdek, 1981), applied to the model produced at a user-defined iteration of the smooth inversion, in order to simplify the density variation pattern and to retrieve a set of interfaces separating geological units. This set of interfaces are used to design appropriate gradient matrices applied in a second inversion phase to sharpen the smooth solution. The above strategies are applied, and their results compared, on several synthetic cases and on a real microgravity dataset related to a shallow buried segment of the Irpinia fault.

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Analysis of the San Giuliano di Puglia (Southern Italy) active faults: an integrated approach

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Keywords: Multiscale potential field analysis Mattinata fault Seismogenic faults,

The area of San Giuliano di Puglia (Southern Italy) was struck by a moderate earthquake of Mw=5.7 on October 31st, 2002. The aim of this study is to identify and better constrain the geometry of the seismogenic structures (active, outcropping and buried faults) in the area. We used an integrated analysis of geo-structural, seismic and gravimetric data.

We built three thematic databases: “faults”, “earthquakes” and “gravimetric" data:

1. The fault database consists of data extracted from the available structural and geological maps: ITHACA (ITaly HAzard from CApable faults) catalogue; DISS (Database of Individual Seismogenetic Sources) database; the "Neotectonic Map of Italy" 1:500.000; the Geological Map 1:100.000, Sheets 154, 155, 162, 163; several geological studies.
2. The earthquakes database was created by merging the data from historical and instrumental Catalogues (CPTI11; ISIDE-INGV).
3. The gravimetric database was created through the Multiscale Derivative Analysis (MDA) of the Bouguer anomaly map of the area, whose maxima show the presence of density lineaments.

The integration of these datasets in GIS environment, identified three possible cases of correlation between faults, earthquakes and MDA maxima:

- A clear correlation between epicentral location, fault positions and MDA maxima shows the existence of active faults;
- A good correlation between MDA maxima and epicentral positions, without correspondence with faults known from geological data, can suggest the presence of buried active faults;
- A good correlation between faults from geological datasets and literature and MDA maxima, without correlation with earthquakes, can indicate the existence of inactive or silent faults.

Previous studies show that the main shock in the area of San Giuliano di Puglia was generated by a deep and sub-vertical strike-slip structure E-W trending, with a right lateral focal mechanism (Galli & Molin, 2004). Nevertheless, Vezzani et al. (2009) proposed a reverse fault mechanism. Valensise et al. (2004) suggested that the 2002 events could be related to the Mattinata fault, a major active right lateral strike-slip fault cutting across the Gargano promontory, In order to better constrain the structural framework of this area, we combined faults seismic data and a multiscale approach of gravity data in GIS environment.

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Tectonic Carving in fault zones: its contribution to glaciotectonic erosional processes

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Keywords: Regional fault zones structure, East Antarctic Craton Cenozoic Tectonics, Monte Carlo modelling.

In this work we present the analysis of the footwall morphology of the Concordia subglacial extensional fault in the East Antarctic Craton. The Concordia Fault is a regional fault zone that extends for almost 200 km showing a displacement, up to 1800 m and a listric geometry responsible for the marked asymmetry that characterizes the corresponding scarp in the Concordia Subglacial Trench (CST). Radio Echo Sounding (RES) profiles across the CST show that the portion of the footwall in the proximity of the master fault exhibits an excavated morphology, about 500 m deep and up to 5 km wide, showing strong correlation with the master fault displacement. We explored the possibility that this morphology may result from the combined action of fault-induced fracturing and passive clast removal and scattering by flow and plastic deformation within the ice sheet.

The introduced Tectonic Carving (TC) process can easily take place and preserve in the prevailing negligible erosion/deposition conditions at the base of the East Antarctic Ice Sheet (EAIS) that prevents from other exogenous mechanisms of erosion, transport, and deposition. The TC, differently from the regressive glacio-fluvial erosion, is negligible in the valley bottom.

Using a Monte Carlo modeling approach we selected the set of parameters that best fits the data set with the carving theoretical curve. The final results of the Monte Carlo analysis show a RMS of about 50 meters, comparable with the data resolution.

Our modeling shows that tectonic carving relates to the relative fracture intensity in the Concordia fracture zone, that corresponds to the envelope of master and secondary fault damage zones. Fracture intensity depends on the frequency and the displacement of secondary faulting and can be approximated by a normal distribution. The described behavior of fracture zones resembles, at a different scale, the behaviour of damage zones around faults, similarly characterized by a decreasing of fracture intensity with distance from the main displacement surface.

This analysis demonstrates a method to unravel the presence of fracture zones in similar, weak erosional environments. The EAIS conditions represent the ideal environment where the contribution of the tectonic carving on the bedrock morphology in fracture zones, as around regional faults, can be analyzed independently of other exogenous factors.

Results from this study provide new constrains on the tectonic origin of the Concordia Subglacial Trench in this still open debate. This evidence is represented by the singular morphologies found on the footwall side of the valley and produced by the tectonic carving, constraining the age of the Concordia Fault activity at the onset of the ice sheet in Oligocene times (around 34 Ma). The alternative hypothesis might be a relatively younger age of the Concordia Fault activity that erosion was unable to obliterate.

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The San Benedetto-Gioia dei Marsi (Fucino, central Italy) shear zone

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Keywords: Fault zone textural properties, Active fault, Fucino, Abruzzi.

Brittle shear zones in carbonate rocks are variably characterized as regards their textures, porosity and fractures: particularly, details of how these property vary moving along and normal from main fault planes, i.e. from fault cores into damage zones, are lacking. Here, we have investigated the shear zone associated to the central portion of the San Benedetto–Gioia dei Marsi (SBGM) fault (Fucino Plain, central Italy) in the Venere quarry. The SBGM is an active normal fault located along the eastern border of the Fucino basin, and is considered responsible for the large 1915 earthquake (Mw 7.0) that struck central Italy. The Venere quarry offers an exceptional opportunity, since it allows visualizing the shear zone in a nearly 3D outcrop. The shear zone, which is about 100 m wide and is exposed by the excavation activities for a length of some hundreds of meters, consists of fault planes and cohesive, fractured and pulverised carbonate rocks.

We have firstly carried out detailed field measurements of clast size frequency through scan areas. On the basis of these early observations, we collected several oriented representative samples along the main fault, within its core and the damage zone, and within the undeformed bedrock for laboratory analysis. The textural parameters were investigated at different scales to have a full range appraisal of their features. We observed mesoscopic features on polished surfaces with areas of few dm^2 and on microscopic images from thin sections (areas of few tens of cm^2) collected either with optical and scanning electron (SEM) microscopy. Textures were quantified by image analysis, and namely abundance (% area), aspect ratio and long plus short axes of equal-area ellipses corresponding to tectonic grains from dm (scan areas) to micrometric sizes (SEM micro-photographs). In addition, the porosity of the same macroscopic samples was measured through Hg-porosimetry.

Cataclastic rocks characterize the grain size distribution of this portion of the SBGM. However and interestingly, textural variations are evident at different scales of observations both along and, especially, moving away from the main fault. The main fault is characterized by a higher amount of large grains (> 2 mm) than the damage zone samples; in addition rock samples on the main fault shows differences in grain size distribution along strike. In parallel, the porosity of the main fault rocks is low (normally < ½, up to 6 vol.%), undeformed sedimentary samples are invariably < 1 vol.%, whereas damaged and pulverized rocks show pores up to about 10 vol.%. These results unravel that rock textures in the shear zone are very variable and reflect complex deformation processes. The actual features of a carbonate shear zone can be more properly captured studying rocks along strike and normal to the fault plane.

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Fault populations growth within the Upper Pliocene-Lower Pleistocene lacustrine deposits of the Aterno Valley graben system (Castelnuovo, L'Aquila)

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Keywords: Aterno Valley, Fault growth, Structural analysis.

During the Mw 6.3 L'Aquila 2009 earthquake the Castelnuovo village suffered high amplifications and damages mostly due to the diffuse presence of anthropic caves beneath the buildings, that in many cases collapsed. Such cavities are carved into upper Piacenzian-Gelasian silty lacustrine deposits (*San Nicandro Fm.*) which represent the base of the Plio-Quaternary infilling sequence of the Aterno Valley graben system (*e.g.*, Giaccio et al., 2012).

The caves that have remained accessible offer a very good exposure of the lacustrine deposits affected by high-angle (up to vertical) fractures and shear planes arranged in two main trends: NNW-SSE and NE-SW. Shear planes determine normal displacements with throws up to 10-15 cm, well evidenced by ochraceous sandy levels interlayered within white silts, and are sometimes organized into sub-vertical graben-like systems. The 3D exposure of the faults allows analyzing the throws distribution both along strike and dip of fault planes. They develop for lengths of up to few tens of meters, growing both from surface to depth and vice versa, in agreement with classical displacement/length relations for tectonic faults. Faults often show en-échelon patterns and linkage relations, according to typical propagation models for cracks. It is to note that during seismic shaking fractures and shear planes represent preferential surfaces that favor blocks separation and collapses, especially when conjugate and transverse systems cross cut isolating large wedges of rocks.

NNW-SSE-trending structures seem to represent the main fault population, probably associated to a secondary splay of the Barisciano-San Pio master fault. This orientation is compatible with the post-orogenic Quaternary extensional field and with the trend of the major Quaternary normal faults affecting this sector of the Apennines. Furthermore, field studies integrated by geophysical surveys (seismic noise, ERT) and borehole data, provided a better understanding of the fault zone and the sediment-bedrock boundary.

Summarizing, our observations can be explained by the occurrence of a discrete fault zone developing above a shallow blind fault, probably at the top of Meso-Cenozoic carbonate rocks, which produces brittle deformation within the overlaying poorly lithified and probably unsaturated lacustrine sediments. Although the collected data suggest a tectonic significance for these structures, the influence exerted by loading and seismic shaking cannot be excluded. The lack of upper Quaternary deposits affected by faulting, as well as no clear morphotectonic evidence in the study area, support an "old age" activity for this fault zone, *i.e.* possibly referred to the Early-Middle Pleistocene development of the Aterno Valley graben system.

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The 1976 Guatemala earthquake: a validation of the ESI scale through re-evaluation of the event based on probabilistic and deterministic hazard analysis

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Keywords: earthquake, central America, probabilistic and deterministic analysis, hazards, ESI-07 scale.

The progress and development of research in the field of earth sciences provides a new set of effective tools to understand and prevent the seismic hazard. Especially in the last years, a substantial improvement has been achieved, thanks to the ground motion prediction equation proposed by the NGA-project, along with faster computers, GIS software and the new intensity scale ESI-2007 (Michetti et al., 2007). The aim of this study is to re-evaluate the hazard for one of the most severe events in Guatemala, by integrating: 1) the recorded data; 2) the coseismic geological effects in terms of ESI scale intensity values; 3) the ground shaking data estimated by probabilistic/deterministic approach.Guatemala is one of the most seismically active countries of Central America and during the last century several strong earthquakes hit the country with dramatic consequences. The most destructive event occurred on February the 4th, 1976, with the activation of the 230 km Montagua fault, and caused about 23,000 deaths, and 77,200 injuries (Espinosa,1976). Severe grounds effects that permanently changed the landscape also characterized this earthquake (Espinosa,1976; Harp et al., 2011; Porfido et al., 2015a). In order to better constrain the Guatemala earthquake destructive path, we have investigated an area of about 18,000 Km^2, in terms of damage affecting housing and infrastructures, and integrated this information with the ground surface effects such as faults, landslides, grounds cracks and liquefactions. Based on the re-evaluated intensity distribution over 24 localities, a new epicentral area characterized by XI ESI, has been defined (Porfido et al., 2015,a,b). Furthermore, a probabilistic/deterministic hazard analysis (Bonito et al,. 2012) was conducted for the target area in order to calculate the geographical distribution of a series of ground motion parameters (i.e. PGA, PGV, SA) that have been compared with the recorded seismological data and integrated with the ESI intensity evaluation.

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High Resolution seismic method for detection and understanding of suspected active blind faults: the case of Terme Caronte geothermal area (Lamezia Terme-Calabria, Italy)

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Keywords: fault zones, earthquake hazard assessment, High Resolution seismic reflection method, buried faults.

A crucial task in earthquake hazard assessment is the problem of investigating buried main faults and secondary features to evaluate their seismic hazard potential, because they cannot be easily detected by surface geological analyses.

The Lamezia Terme territory, located in the westernmost edge of the Neogene-Quaternary “Catanzaro Trough”, is influenced by the presence of different major trascurrent/oblique faults which belong to the Lamezia Terme-Catanzaro Fault (LCF), a NW-SE trending seismogenetic trascurrent fault zone.

The subsurface geometry of LCF is recognizable on a morphological basis and constrained by commercial profiles (VIDEPI Project); however, quality of commercial reflection profiles is often inappropriate to face the extreme structural complexity related to this seismogenetic zone. Although these geophysical surveys have provided insight into the large-scale geology, resolvable with high-energy and low-frequency seismic acquisition systems, only high-frequency seismic studies at specific sites can resolve the fine-scale features required to interpret Quaternary processes.

In Lamezia Terme area, in fact, the outcropping heterogeneous Quaternary terrigenous successions probably absorbed the rupture’s stress related to historical fault activity; this do not permit to delineate active faults with the traditional geological mapping and/or paleoseismic investigation.

High Resolution (HR) seismic reflection method, integrated with a pure surface geology approach, can overcame the problem of absence of clear geomorphological/stratigraphic indicators of synsedimentary fault activity, permitting a detailed structural imaging at shallow depth, which is crucial to document recent activity and assess seismogenic potential of blind faults.

In Lamezia Terme area, since no detailed information on the faults segment which cross this zone is available, was identified a sector, 600 m-wide (but the extension of the zone is uncertain), subject to environmentally protective restrictions due to the presence of LCF.

Therefore, in order to improve the imaging of shallower more recent sequences, we acquired, at "Terme Caronte", near the village of Sambiase, four HR seismic reflection/refraction profiles (total length about 1500 m).

Seismic data were collected by a Swept Impact Seismic Source (VibSist-500), appropriate for shallow reflection surveys, and an array of receivers consisting of 96, 4.5 Hz, vertical geophones. Setting the receiver spacing to 5 m and the source interval to 10 m, we recorded dense data within a wide offset range.

This study aims to develop an improved seismic stratigraphic framework for Lamezia Terme area in order to recognize seismic units distribution and the possible presence of buried fault segments linked with the principal displacement zone, which are fundamental information for a quantitative approach to seismic hazard assessment and the subsequent land-use planning.

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Fault zone characteristics in tight siliciclastic turbidites: an outcrop study on the Macigno Formation, Tuscany, Italy

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Keywords: fault zone characteristics, turbidite, siliciclastic rocks.

Faults in siliciclastic rocks are characterized by great variability of fault zone architecture and relative permeability properties. This is because siliciclastic rocks (i.e. turbidite successions) are commonly represented by alternating layers of various thickness and grain size, forming successions with contrasting mechanical properties. For example, the alternation of sandstone and mudstone layers is responsible for the simultaneous occurrence of brittle and ductile deformation, as “clay smear structures.” Moreover, numerous studies have identified grain size as one of the main influencing factors for fault nucleation processes and fracture intensity in fault damage zones (Nelson, 2001; Welch et al., 2009).

We present the results of field and laboratory analyses of the Macigno Formation cropping out along the western coast of Tuscany. Here, the Macigno Formation is represented by tight, Late Oligocene foredeep siliciclastic rocks dominated by turbidite sandstones with minor siltstones and black shales. These rocks are heavily fractured and affected by several sets of normal to strike-slip faults with different degrees of development (from incipient simple discontinuities with mm-offset to fault zones with tens of meters offset and well-developed fault cores and damage zones). We have documented varying fault zone properties in different turbidite lithofacies associations.

The thickness of sandstone and siltstone/shale beds varies from tens of centimeters up to 4 meters and from several centimeters to tens of centimeters, respectively. Thin section and 3D X-ray Synchrotron microtomography allow us to characterize grains, especially their geometrical and morphological properties (e.g. size, shape, specific surface area). We document how thickness, grain size and mechanical properties of alternating beds strongly control fault zone architecture, especially in terms of fault core composition and texture, damage zone thickness and fracture intensity and height. Furthermore, the development of clay smear structures is enhanced by the presence of thin siltstone/shale layers alternating with sandstone ones.

The rock physics of hard rocks: from reactive fluids in volcanic regions to high-performance concrete-like rocks

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Keywords: Geothermal Systems, Hard Rocks, Fibrous Rocks, Rock Strength.

The caldera of Campi Flegrei is one of the active hydrothermal systems of the Mediterranean region experiencing notable unrest episodes. Despite the large uplifts, the release of strain appears delayed. Seismicity become prominent reaching a magnitude of 4.0 only upon relatively large uplifts (70-80 cm), contrary to what is generally observed for calderas exhibiting much lower deformation levels. Over and above the specific mechanism causing the unrest and the lack of identification of a shallow magmatic reservoir (< 4 km) by seismic data, there is a core rock physics question of how the subsurface rocks of Campi Flegrei withstand a large strain and have high strength. In other words, why the subsurface is capable of accommodating such deformation without immediately releasing the stored energy through rock fracturing or cracking? What is the rheological scenario that connects these observations? Answering these questions is important not only for studying deformation and seismicity in volcanic-hydrothermal systems but also for conserving Earth's life support systems such as characterizing energy resources in hard rocks more efficiently as well as devising greener concrete with enhanced performance.

We performed a series of direct measurements on deep well cores by combining high-resolution microstructural and mineralogical analyses with the elastic and mechanical properties of well cores from the deep wells drilled in the area right before the unrest of 1982-1984 - San Vito (SV1 and SV2) and Mofete (MF1, MF2, MF5). The rock physics analysis of the well cores provides evidence for the existence of two horizons, above and below the seismogenic area, underlying a natural, coupled process. The basement is a calc-silicate rock housing hydrothermal decarbonation reactions, which provide lime-rich fluids. The caprock above the seismogenic area has a pozzolanic composition and a fibril-rich matrix made of intertwining filaments of ettringite and tobemorite, resulting from lime-pozzolanic reactions. These findings provide evidence for a natural process reflecting that engineering the mortar of the Roman concrete.The formation of fibrous minerals by intertwining filaments confers shear and tensile strength to the caprock, contributing to its ductility and increased resistance to fracture. The importance of the findings reported in this study lies not only on the fibrous and compositionally nature of the caprock but also on its possible physicochemical deterioration. Given the P-T-XCO_2 conditions regulating the decarbonation reactions, the influx of new fluids into the Campi Flegrei system lowers the temperature of the decarbonation reaction and dilutes the existing CO_2, thus triggering additional CO_2, methane, and steam to form. As these gases rise toward the surface, the natural cement layer halts them, leading to pore pressure increase and subsequent ground deformations.

http://www.sciencemag.org/news/2015/07/natural-rock-near-naples-italy-may-have-inspired-roman-concrete

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Neogene paleoseismicity in the Elba Island exhumed geothermal system (Italy): insights from the Monte Calamita area

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Keywords: Paleoseismicity, Fault mirror, Exhumed geothermal system.

Geothermal systems are characterized by active seismicity, that is necessary for maintaining an efficient permeability. Although recognition of paleoseismic features is always rare in any tectonic context we report the evidence of co-seismic activity of a tourmaline-quartz bearing fault, as it is highlighted through micro to nano-scale structures of the slip zone.

Our data are from a Messinian-Pliocene fault affecting the Elba Island Paleozoic micaschists, the deepest outcropping rocks of inner Northern Apennines. This micaschist is considered the analogue of the rock hosting the deep reservoir of the present Larderello geothermal system.

Faults under study are part of the NW-striking faults system characterized by up to 15 cm thick tourmaline+quartz+goethite shear veins. Superimposed mechanical striations characterize faults surface, with kinematics from oblique to normal-slip movements. The last movement gave rise to mirror-like surface on the study tourmaline shear veins, mainly composed of tourmaline crystals with interstitial goethite. The mirror surface, a few µm thick, is formed by naturally polished tourmaline crystals, and is characterized by: 1) disappearance of interstitial goethite; 2) highly variable grain size, from 200 µm to 200 nm; 3) compact impinged microstructure and 4) tourmaline random crystallographic orientation.

Deformation in the fault zone was investigated from the outcrop to the nano-scale. It revealed the superposition of brittle process, giving rise to a principal clastic/ultracataclastic slipping zone, few mm thick. Such a process determined localized decomposition/recrystallization effects, responsible for the formation of the polished mirror surface itself. Tourmaline mirror faults represent therefore the traces of ancient earthquakes and, similarly to other mirror faults, they can be considered as the micrometer-sized products of a “seismic metamorphism”, with mineralogy and micro/nanostructures variable as a function of protolith (i.e., the fault rock) and “metamorphic” conditions (e.g., slipping rate and T rise by frictional heating).

By this study we emphasise that the key elements of paleoseismicity can also recognized in epi- and meso-thermal fossil geothermal system thus enforcing the importance of the study of fossil geothermal system as a key for the understanding of the active ones.

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SESSION S4

Fluid-rock interactions: metamorphism, geothermal resources, faulting processes and induced seismicity

CONVENERS AND CHAIRPERSONS

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May engineering activities located in Sicily (Southern Italy) "potentially" induce seismicity?

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Keywords: "triggered" earthquakes, "induced" earthquakes, engineering activities.

Earthquakes caused by human engineering activities are commonly termed as "triggered" or "induced". This class of earthquakes, though characterized by low-to-moderate magnitude, have significant social and economical implications since they occur close to the engineering activity responsible for triggering/inducing them and can be felt by the inhabitants living nearby, and may even produce damage. One of the first well-documented examples of induced seismicity was observed in 1932 in Algeria, when a shallow magnitude 3.0 earthquake occurred close to the Oued Fodda Dam (Gupta, 1985). By the continuous global improvement of seismic monitoring networks, numerous other examples of human-induced earthquakes have been identified (see Davies et al., 2013 for an overview). Induced earthquakes occur at shallow depths and are related to a number of human activities, such as fluid injection under high pressure (e.g. waste-water disposal in deep wells, hydrofracturing activities in enhanced geothermal systems and oil recovery, shale-gas fracking, natural and CO_2 gas storage), hydrocarbon exploitation, groundwater extraction, deep underground mining, large water impoundments and underground nuclear tests (Davies et al., 2013). Despite the presence in the Sicilian territory of a large amount of engineering activities "potentially capable" of inducing seismicity, no extensive researches on this topic have been conducted to date. Hence, in order to improve our knowledge, and correctly assess the hazard at a specific location in the future, we started a preliminary study on the main engineering activities located on- and off-shore of Sicily (Southern Italy). To this end, in a first step we collected all the useful information coming from available on-line national and regional catalogues. The compiled database includes 46 dams, 598 quarries and 839 oil and gas wells for a total of 1483 engineering activities. Among these, 175 are located along the southern Sicilian coastal off-shore while the remaining 1308 are located inland. As a second step, we performed a detailed compilation of instrumental seismicity striking the investigated area. Continuous seismic monitoring of the whole Italian territory started in the 90s and is currently performed by the National Seismic Network managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). In addition, monitoring and systematic analysis of seismic activity in eastern Sicily, by means of a dense local network, is performed also by the "Osservatorio Etneo" (INGV-OE), an INGV-branch located in Catania, close to Mt. Etna. Since 1983, earthquakes occurred in the entire Italian territory have been analysed and archived in the catalogue managed by the INGV headquarters in Rome (INGV-CNT; Castello et al., 2005; ISIDe Working Group - INGV, 2010), while since 1999, earthquakes occurred in eastern Sicily have been analysed and archived in the database of the INGV-OE (Alparone et al., 2009; Gruppo Analisi Dati Sismici, 2016). Because the INGV-OE catalogue covers with great details only the eastern sector of Sicily, while the INGV-CNT catalogues, extends back in time since 1983, in order to identify possible prospective effects of the human activities on the seismicity, here we took into account both catalogues. We considered only the seismicity occurred within the first 10 km of the crust because the induced seismicity should be likely confined in the shallower crust. As a final step, in order to identify prospective effects of the human activities on the seismicity, we investigated the spatio-temporal relationships between engineering activities and earthquakes, by adopting a statistic approach aimed to the detection of anomalous seismicity densities. Finally, we identified 46 engineering activities (2 dams, 16 wells and 28 quarries) characterized by anomalous seismicity density. These activities are mainly located in Western Sicily and on the eastern sector of the Hyblean Plateau, while a few number of activities are locate in northern Sicily and on the Island of Vulcano. Currently, we are performing detailed analyses on the nature of the observed seismicity activity in proximity of these engineering activities.

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Reservoir structure and induced seismicity at the Val d'Agri oilfield (Southern Italy) shown by local earthquake tomography

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Keywords: Southern Apennines, Local Earthquake Tomograpghy, Apulian reservoir structure, injection induced.

The Val d'Agri (VA) Quaternary basin in the southern Apennines hosts the largest oilfield in onshore Europe and normal-fault systems with high seismogenic potential. Small-magnitude swarms related to active crustal extension and anthropogenic activity have occurred in the region. Causal factors for induced seismicity are the Pertusillo water impoundment located at the southern margin of the oilfield and a wastewater injection well (CM2 well).

We analyzed 1200 local earthquakes (M_L<3.3) recorded from 2001-2014 in the Val d'Agri and surrounding regions by up to 60 local stations belonging to 3 different networks: a dense temporary network operated by INGV (2005-2006), the National Seismic Network operated by INGV and a permanent monitoring network managed by the local industry operator.

We used Local Earthquake Tomography (LET) to obtain high-quality Vp and Vp/Vs images of the oilfield and to accurately locate seismicity. Vp and Vp/Vs models parameterized by a 2X2X1 km spacing are well resolved down to about 8 km depth.

Broad antiformal structures characterized by high Vp (5.6-6.2 km/s) and high Vp/Vs (up to 2.0) encircle the basin between 2 km and 4 km depth. Such structures relate to main culminations of the Inner Apulia Platform (IAP) reached by deep wells at around 2 km depth b.s.l. under both basin-bounding ridges. We interpret these high-Vp structures as wide ramp-anticlines of the IAP developed during Pliocene shortening. Very high Vp bodies (up to 6.5 km/s) imaged between 4-8 km depth are likely composed of Triassic evaporites at the base of the IAP.

The IAP anticlines correspond to high Vp/Vs regions (Vp/Vs > 1.95). This suggests the presence of highly fractured carbonates saturated by liquid-bearing fluids with high pore pressure. Very high Vp/Vs spots detected in injection area can be related to the disposal activity into well CM2.

The seismicity mostly concentrates between 2 km and 5 km depth and shows a remarkable clustering within high-Vp, high Vp/Vs regions confined within the Apulian reservoir.

Focal mechanisms show predominant normal faulting kinematics with minor strike slip solutions in agreement with the local extensional stress field. Earthquake locations and focal solutions depict shallow (< 5 km depth) NE-dipping extensional structures south of the Pertusillo lake and along Monti della Maddalena ridge. A few swarms define relatively deep transfer structures beneath the oilfield accommodating the differential extension between main normal faults. The spatial distribution and kinematics of the induced seismicity beneath the well CM2 remarkably indicate a ~50° NE-dipping fault structure confined within the IAP. Its geometry is consistent with the general trend of back-thrusts interesting the antiform drilled by the well CM2. We suppose that injection-linked seismicity (M_L < 2.3) relates to small fault-patches of an inherited fault zone (e.g. Pliocene back-thrust) that is optimally oriented in the active extensional stress field.

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Underground geological structures of Val d'Agri (Southern Apennines, Italy) and their relationship with natural and induced seismicity

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Keywords: undeground structures, induced seismicity, Val d'Agri, Southern Apennines.

The Val d'Agri Quaternary basin is located within the southern Apennines extensional belt, hosting the largest oilfield in Europe. Recent studies on background seismicity reported for this region an intense low-magnitude activity concentrated in the southern portion of the basin. Earthquakes are mostly induced by anthropogenic activities, which are represented here by seasonal variations of the Pertusillo water impoundment (e.g. reservoir induced protracted seismicity, $M_L < 3$) and wastewater injection into an oilfield disposal well ($M_L < 2.3$). Conversely, natural micro-seismicity occurring to the west of the basin suggests on-going deformation along a normal-fault system that cuts across the Monti della Maddalena ridge (Monti della Maddalena Fault System, MMFS).

In this study we perform a detailed analysis of subsurface exploration data (2D/3D seismics and deep wells) to define a reliable 3D geological model that could help understanding the relationship between fault structures and the natural/induced seismicity occurring in the southern portion of the basin.

Below the wastewater injection site, the Apulian carbonates representing the injection reservoir are interested by a SW-dipping moderate-angle thrusts and associated back-thrusts system inherited by a Plio-Pleistocene compressional tectonic phase. The entire thrust system is located in the footwall of the Quaternary extensional Eastern Agri Fault System bounding the basin on its eastern flank. A NE-dipping back-thrust is well imaged just below the injection site, while its geometry is coherent with the hypocentral alignment of injection-linked events.

The spatiotemporal distribution of injection-related events suggests that wastewater disposal activity firstly caused the reactivation of the deeper portion of the back-thrust; then seismicity migrated up-dip remaining almost confined within the Apulian units.

Focal mechanisms show a predominant extensional kinematics in agreement with the local extensional stress field defined by surface and borehole breakouts data. Induced events occurred on a small and high-permeability patch of the back-thrust, favorably oriented with respect to the present-day extensional stress field.

The analysis of the relationship between earthquakes occurring along the Monti della Maddalena ridge and to the south of the Pertusillo artificial lake and subsurface structures highlights that those events concentrate within the Apulian carbonates. Besides, accurate 3D locations of natural and induced seismicity delineate possible NW-SE trending fault segments that are coherent with southern splays of the MMFS imaged by seismic exploration data. Prevailing NW-SE trending normal-faulting focal mechanisms support this interpretation, while an evident cluster characterized by strike-slip solutions (M_{Lmax}=2.9) suggests the presence of a NE-SW trending high-angle transfer fault that cuts the extensional structures.

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Modeling and imaging of induced-microseismic events

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Keywords: microseismicity, modeling, imaging.

Seismic emission during fluid injection has been observed in fracking of unconventional reservoirs, stimulation of geothermal fields and CO_2 storage. The generation of microseismic events is associated with the development of micro-cracks or faults due to the flow. A full characterization of the spatio-temporal distribution of microseismic events yields the location of fluid-induced seismicity and provides valuable information about the medium, such as its hydraulic diffusivity. Injection induces a pore-pressure build-up around the borehole that generates tensile and shear micro-earthquakes which emit P and S waves if given pressure thresholds are exceeded. We develop a simple model to simulate micro-seismicity in a layer saturated with brine, based on an analytical solution of pressure diffusion and an emission criterion for P and S waves. The model is based on poroelasticity and allows us to obtain estimations of the hydraulic diffusivity on the basis of the location of the micro-earthquakes and the triggering time. Wave propagation of P and S waves is simulated with a full-wave solver, where each emission point is a source proportional to the difference of the pore pressure and the tensile and shear pressure thresholds. A reverse-time migration algorithm is outlined to locate the asynchronous sources induced by the fluid flow.

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Geothermal exploitation and fluids withdrawal/reinjection: a numerical modelling for implication on induced seismicity

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Keywords: geothermal, induced seismicity, injection, reinjection, withdrawal, fluid stimulation.

Induced seismicity can be associated to the activity of fluid withdrawal and injection from/into the shallow crust (fracking, wastewater disposal into the deep crust, EGS technology, fluid extraction in oil fields and geothermal power plants). The variation of pressure and its volumetric propagation, due to fluids stimulation, is here analysed to assess the potential for induced seismicity. A set of simulations of withdrawal/injection/reinjection cycles from/into the same reservoirs, by using the numerical code TOUGH2®, is applied to conceptual models of different geothermal reservoirs. The aim is to compare the time growth of perturbed volumes obtained with withdrawal-reinjection cycles to those obtained during simple withdrawal or injection, using the same flow rates. Our results clearly show that withdrawal-reinjection is by far less critical than simple injection or withdrawal, because the perturbed volumes are remarkably smaller and remain constant over the simulated time, so minimizing the likelihood of interference with seismogenic faults. Our outcomes have significant implications in the application of new geothermal projects, such small size (5MWe) binary power plants.

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Groundwater flow and low enthalpy geothermal resources: the case study of Marche (Central Italy)

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Keywords: Geothermal resources, groundwater flow, thermal conductivity, convection, Marche region.

In the frame of the renewable energy resources, geothermal heat pumps coupled with borehole heat exchangers (BHEs) are an increasingly technology whose performances are under investigation. The underground heat transfer processes are commonly assumed to be dominated by conduction. However, groundwater flow can strongly affect the underground thermal conductivity, which is of fundamental importance in planning BHEs. In this paper, we address this issue and propose an approach to predict, on a regional scale, the possible behaviour of BHEs in relation to the hydrogeological conditions. The approach relies on the joint analysis of thermal and hydrogeological information. Due to its hydro-geological variability, we chose Marche as a valuable test area to implement a general methodology of study. First, we carried out laboratory measurements of thermo-physical properties (conductivity, diffusivity, porosity, and density) of samples of the main geological formations. Since laboratory measurements were technically difficult on some lithotypes, alternatively we performed mineralogical determinations through XRD diffraction and applied mixing models to infer the thermal conductivity. As a whole, laboratory results and indirect estimations yielded a comprehensive picture of the thermal conductivity expected for the sedimentary lithotypes of the Umbria-Marche succession. Besides, the combination of these results with lithostratigraphic information, gave a first insight into the possible thermal behaviour of the underground. We then collected and analysed hydrogeological data, including maps of piezometric levels, available hydraulic conductivity values from in situ-tests in selected boreholes, time series of groundwater physical properties (temperature and electrical conductivity). The analysis of these data gave a general picture of the hydrogeological setting of the region and in combination with seismostratigraphic data suggests that the deep geological structures could be a factor influencing the groundwater flow paths. The hydrogeological data were gridded and interpolated to produce a Darcy velocity model of the main regional aquifers. Finally, the effect of groundwater flow on the heat transfer between BHEs and the ground was estimated by applying the Nusselt and Reynolds numbers analysis to some selected areas where detailed hydro-stratigraphyc information were known. The adimensional number analysis shows that conduction is expected to dominate in aquifers with Darcy velocity < 10-6 m s-1, (e.g. micritic limestones of the Corniola Fm. and marly lithologies like "Schlier" Fm.) while advection becomes the most important heat transfer mechanism for Darcy velocities > 10-4 m s-1, like it occurs in the alluvial deposits. In summary, the coupled analysis of thermophysical and hydrogeological data appear as a useful tool for predicting the type of thermal regime at shallow depth and therefore evaluating the possible role of advection in BHEs systems.

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The dewatering of the Fucino lake (1875) and the occurrence of the M7 Fucino earthquake (1915): is there any relationship?

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Keywords: faulting, induced seismicity, stress change.

We explore the possibility of a relationship between the dewatering of the great lake that formerly occupied the Fucino intermountain basin (Central Italy) and the occurrence of seismicity recorded in the area since the 20th century and culminated with a M7 earthquake in 1915 (Cucci & Tertulliani, 2015). The Fucino lake occupied an area of almost 150 km^2 with a rather constant depth of ~20 m; it was the largest lake of peninsular Italy. To definitely prevent the area from frequent severe floods it was completely drained in 1875 following an ambitious engineering project lasted twenty years.

The Fucino earthquake hit on 13 January 1915; it represents one of the most destructive seismic events ever occurred in Central Italy (Mw 7, I XI; Rovida et al., 2011). This event aroused a large interest because it affected a part of the Apennine chain characterized, from a historical perspective, by a very modest seismicity (Baratta, 1915; Rovida et al., 2011). Therefore, the event surprised a completely inadequate building stock (Oddone, 1915), causing about 30.000 fatalities and the nearly total destruction of many villages within a large area, including the city of Avezzano. More than 230 localities suffered destructions and damage estimated greater or equal intensity VIII MCS.

The research carried out in this study is as following:

-Historical seismicity: an in-depth revisiting of the seismicity occurred in the area since the 19th century, aimed at an improvement of the database of the microseismicity, and at a more accurate localization of the stronger events.

-Characterization of the seismogenic source: we provide an improved characterization of the potential seismogenic source, by taking into account all available geological, paleoseismological, geodetic data modelling and hydrogeological observations.

-Coulomb stress change (CSC): a numerical poroelastic model is investigated to estimate the stress changes induced by the dewatering of the Fucino lake. The numerical simulations provide a computational framework to estimate the amplitude, extent and temporal scales of the medium response. The CSCs are computed along the seismogenic source to assess likely relationship between pore pressure variations and seismicity.

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Thermal waters in the aquifers of Mt. Massico (Campania Region, southern Italy): hydrogeochemical and isotopic ($^{87}Sr/^{86}Sr$) characterization

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Keywords: Thermal Waters, Mt. Massico, Water Geochemistry, Thermal Resources.

Mt. Massico Ridge is a NE trending carbonatic horst in the northern Campanian region (southern Italy). On its NE flank, the Roccamonfina volcano developed from 500 to 150 Kyr BP. Widespread evidences of geothermal fluids emissions (sink holes, CO_2-rich springs, thermal waters) are also present. During a preliminary hydrogeological survey of the area, several shallow and localized aquifers have been detected in the volcanic and in the alluvial deposits. A main carbonate aquifer has been identified in the NE sector of the ridge. This aquifer is relatively cold (17°C) and shows low mineralization (EC ~400 µS/cm). In the central part of the Mt. Massico aquifer (Falciano del Massico city) a temperature increase up to 26°C has been observed. As a whole about twenty-five water samples have been sampled from wells located in the Mt. Massico area and analyzed to determine the hydrogeochemical and isotopic (87Sr/86Sr) compositions. Water samples from the Mt. Massico Thermal Waters systems (MTW) are Mg-Ca-HCO_3 type. Temperature increases together with Cl, SO4, Li, B and Sr contents. The highest temperature water samples has been detected at the intersection of different faults, likely acting as vertical conduits for warm fluids uprising. These fluids are conductive (EC~1800 µS/cm) and show sub-acidic pH (~6.3). It is worth noting that in the Mondragone plain, at the foot of Mt. Petrino, located on the SW border of the Mt. Massico horst, close to the cost, another thermal waters system (known as Padule-S.Rocco, PSR) is located (Cuoco et al., 2015). Although spatially close the MTW temperature is lower (25°C) than that of PSR (32°C). Water samples are dolomite saturated (IS=0) characterized by Mg/ Camolar ratios ~0.4. The Ca+Mg is balanced by the sum HCO_3+SO_4 (i.e. Ca+Mg/HCO_3+SO_4 =1). The PSR waters have strong evidence of dolomite hydrolysis (Mg+Ca/HCO_3=1; Mg/Camolar ratios=0.6) and are supersaturated in dolomite (IS>0). The $^{87}Sr/^{86}Sr$ isotopic composition of the analyzed samples range from ca. 0.7080 to 0.7096, depending on the springing site. Two hypotheses are proposed to explain the dynamics and relation of these systems: 1) the two thermal water systems belong to a common reservoir, their chemical differences being due to the the thermal gradient in the carbonate (dolomite) basement, possibly increasing from the NE flank of Mt. Massico toward the coast or and/or geothermal gases uprising and interacting with waters; 2) the two thermal water systems are separated, and again the warming process is due to their interaction with the geothermal system.

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Fluid inclusions, petrological and structural study of quartz-carpholite veins in the Lungro-Verbicaro unit (southern Apennines, Calabria): from subduction to exhumation

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Keywords: fluid inclusions, quartz-carpholite veins, HP-metamorphism, Southern Apennines, exhumation.

Fe-Mg carpholite, $(Fe^{2+},Mg)Al_2(Si_2O_6)(OH)_4$, is a key mineral of HP-LT metamorphism in pelitic rocks, and typically forms under blue-schist facies in subduction zones. In northern Calabria (southern Apennines), quartz-carpholite veins from the "Scisti del Fiume Lao" Fm (Lungro-Verbicaro Unit, LVU) are reported by Corrado et al. (2010), presenting microthermometric data on fluid inclusions in quartz.

In this study, carpholite-bearing quartz veins hosted by phyllites of the LVU exposed nearby the Maierà village have been analyzed to infer information on the P-T history they experienced during the tectonic evolution of the southern Apennines. SEM-EDS microanalyses has allowed to recognize an association of Fe-carpholite (X_{Mg}=0.34-0.40 apfu), quartz and phengitic white mica (Si=3.15-3.24 apfu, based on ∑O=11) in the absence of chloritoid. Isopleths related to composition of carpholite and phengite have been used to estimate conditions of peak metamorphism at P=1.33-1.5 GPa and T=360 °C. Besides the classical petrological approach, additional information on the thermal history of these rocks has been inferred by fluid inclusion studies. To this end, three samples have been selected: (i) a vein with dominant medium- to fine-grained quartz, a few acicular carpholite, chlorite and white mica; (ii) a vein with coarse quartz and carpholite, chlorite and Fe-oxides; (iii) a phyllite with millimetric finely folded quartz veins. Fluid inclusions have been observed in quartz and carpholite crystals, as well. Different fluid inclusion assemblages (FIAs) are present: (i) large imploded empty cavities with dendritic texture, possibly corresponding to highly re-equilibrated fluid inclusions of first generation, early entrapped at the beginning of subduction; (ii) monophase liquid (L) inclusions; (iii) biphase (L+V) liquid-rich inclusions entrapped during exhumation. Microthermometric analyses of biphase inclusions have allowed to measure the homogenization (Th) and melting temperatures of ice (Tmi). The microthermometric data have been used to reconstruct the isochores for the entire Th and salinity range. Besides, thermal modelling has been applied to reproduce the P-T evolution of the LVU. Finally, by intersecting the isochores calculated from microthermometry with the results of the thermal modelling, the trapping conditions for the analysed fluid inclusions have been estimated. It results that the trapping took place in a late exhumation stage (c. 12 Ma) at P = ca. 0.3 Gpa and T = ca. 300 °C.

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Metamorphic zoning and structural evolution of a contact metamorphism aureole: the example of the Monte Capanne pluton (Elba Island, Tuscany, Italy)

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Keywords: contact metamorphism, metamorphic zoning, plutonic intrusion, magmatic-tectonic processes, Elba.

The Monte Capanne monzogranite (~6.9 Ma, Dini et al., 2002) dominates the geological landscape of western Elba Island (Tuscan Archipelago). This plutonic body is linked to the late-/post-orogenic, essentially anatectic, magmatism of the Northern Apennine chain and is well-known also for the interaction between its uplift (up to shallow level) and the final emplacement of the host tectonic units. It intrudes the basal part of the Ligurian units of the pile of nappes, respect to that one of the Porto Azzurro pluton in eastern Elba hosted in the Porto Azzurro Unit at the bottom of the outcropping tectonic pile (Bortolotti et al., 2001).

This work present the results of a detailed geological survey, petrographical-chemical analyses and meso- and micro-structural observations performed in the entire Mt. Capanne contact metamorphic aureole, outcropping in a at least 400 m-thick discontinuous belt. The rocks of this aureole are made up of a meta-ophiolitic successions (Punta Polveraia-Fetovaia Unit) similar to that of the Monte Strega Unit succession of Eastern Elba (Bortolotti et al., 2001). Despite most of these metamorphic rocks aureole are in the middle to high grade facies (hornblende and pyroxene hornfels), the distribution of the low-, middle- and high- grade hornfels facies was defined for the different lithologies outcropping in the whole metamorphic aureola.

The crystallization of the thermo-metamorphic minerals has occurred in more stages being both syn-kinematic respect to the main intrusion event (D2 folding event) and static post-kinematic. During the intrusion and ballooning of the Mt. Capanne pluton (D1 and D2 events), the development of ductile flattening and shear zones with formation of mylonites and ultramylonites in a general shear-type regime also occurred in a likely transtensile/transpressive regime. The uplift of the cooled pluton produced a final tangential cascade-type folding (the non-metamorphic D3 event), jointing and brittle detachments at different structural levels in the Ligurian host rocks (e.g., Central Elba Fault) and at the contact with the underlying magmatic body. Afterwards, the high-angle Colle Palombaia-Procchio (i.e., Eastern Border Fault) normal fault allowing the final rise of the plutonic mass (D4 event).

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Exploitation of low entalpy geothermal system in structural controlled areas: a sustainability analysis of geothermal resource for heating plant (The Mondragone case Southern Appennines, Italy)

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Keywords: Carbonatic geothermal reservoirs, sustainable exploitation, district heating.

Fault controlled carbonatic extensional domains, largely widespread in Southern Appennines, can represent sites where temperatures for low, middle enthalpy geothermal applications (T < 150C) may be reached at a relatively shallow depths (<0.5 km). The fault controlled geothermal sites are accompanied by hydrothermal activity, hot fluids circulation and mineralization processes. In particular the fracturing and chemical dissolution of carbonates increases the permeability of rocks, enhancing the advection of hot fluids and generating an heat mass transport. In this framework, we analyzed the sustainability of geothermal exploitation in the low temperature geothermal field of Mondragone (CE). This geothermal field and its model were extensively studied trough the VIGOR project (A national project coordinated by the CNR and sponsored by the Italian Ministry of Economic Development -MiSE, dedicated to the evaluation of geothermal poten tial in the regions of the Convergence Objective in Italy: Puglia, Calabria, Campania and Sicily). Piezometric and hydraulic characteristics from well tests, temperatures and groundwater chemical features were obtained, among other parameters, from seismic, geoelettric and hydrochemical analysis and from the drilling of a new deep well (about 300 m). Using the obtained geothermal model a well-doublet open loop district heating plant project was developed for seven public schools of Mondragone town. Finally the thermal perturbation of the reservoir and the sustainability of geothermal exploitation due to extraction and reinjection of fluids, at different depths and temperatures were evaluated for five years of heat plant working using a numerical simulation program (Comsol ®). The results are fundamental in developing a sustainable geothermal energy school district heat plant of Mondragone town and constitute a case study for future developing of geothermal resource in So uthern Italy.

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New geothermal investigations in the Medio Campidano Valley (Sardinia, Italy): geological and geochemical evidences

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Keywords: Sardinia, Campidano, geothermal prospection, fluid geochemistry.

The aim of this work was to define the main geological and geochemical features of the Medio Campidano area (southern Sardinia), providing new data on fluid discharges for potential geothermal exploitation. The multidisciplinary approach included geological field mapping (scale 1:10,000) and fluid geochemistry (spring and well waters and dissolved gases). The study area extends from Guspini-Villacidro – S'Acquacotta (western margin) to Sardara (eastern border) and is characterized by a tectonic-sedimentary pile composed by different units ranging from Cambrian to Quaternary in age.

The crystalline Variscan basement rocks were affected by the Late Oligocene/Early Miocene transcurrence and two rifting events: i) the opening of the Oligo-Miocene southern Sardinian Rift and ii) the successive Plio-Quaternary Campidano graben. Furthermore, Early Miocene calc-alkaline and Plio-Pleistocene intraplate basalts and felsic magmas were emplaced. The hydrothermal circulation in the two sides of the Campidano graben is likely related to such tectono-magmatic events. Consequently, the geological survey mainly focused on different locally fault systems and fractures associated with hydrothermal mineralization and thermomineral discharges. A detailed study of the Pleistocene sediments was also carried out to reconstruct the neotectonic evolution of the Campidano graben.

The chemical compositions of the study waters were Na-Cl(HCO_3) to Na-HCO_3(Cl). The most relevant fluid discharge is the nearly neutral Sardara thermal spring that showed a temperature up to 50 °C and the highest concentrations of HCO_3^- (1760 mg L^{-1}), Cl^- (560 mg L^{-1}) and Na^+ (991 mg L^{-1}) among the sampled waters. The dissolved gas phase at Sardara was characterized by N_2 and CO_2 in almost equal concentrations (50 % by vol.). The isotopic data suggested a common meteoric origin for the Campidano waters (mean values: $\delta^{18}O$ = -6 ‰, δD = -35‰). From a genetic point of view, two different groups of waters can be distinguished:

a) air-saturated (ASW) and N_2-low enriched thermal waters (e.g. Sardara), characterized by a deep mantle contribution ($\delta^{13}C$-CO_2 = ~-6 ‰; $^3He/^4He$=1.22 Ra, Minissale et al., 1999), resulting from long-lasting water rock interaction processes within the Paleozoic rocks;

b) mixing waters between a thermal and a shallow component.

However, such mixing processes, likely occurring in the shallow aquifers hosted in the Tertiary-Quaternary volcanic and sedimentary units, can be envisaged for all analyzed waters.

Finally, by considering an average geothermal gradient of 66.8 °C/km (Loddo et al., 1982) and an equilibrium temperature estimation of ~ 135 °C, based on quartz and Na/Li geothermometers, a relatively long-term circulation into a *reservoir* located at ~2,000 m of depth can be hypothesized.

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From ductile to brittle deformation at blueschist-facies conditions: implications for fluid flow in subduction zones

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Keywords: Mylonite, fluids, ductile-brittle transition, blueschist metamorphism, Western Alps.

This work deals with the study of a blueschist (B) facies mylonite at the contact between two tectono-metamorphic oceanic units (eclogite- and blueschist-facies, respectively) of the Western Alps (Ligurian Alps, NW Italy).

The B-mylonite is a foliated metabasite made up of alternating layers with different grain size and proportions of Na-amphibole, epidote, white mica, Fe-oxide, sphene and quartz.

The B-mylonite foliation formed at peak metamorphic conditions of T = 220-310°C and P = 6.5-10 kbar (estimated through Perple_X pseudosections). The mylonite shows various superposed structures: i) intrafoliar and similar folds; ii) chocolate-tablet foliation boudinage with boudins necks filled by syn-kinematic Na-amphibole +/- quartz; iii) veins with Na-amphibole fibres + minor epidote, sphene and Fe-oxyde; vi) breccia, confined in layers and pods. This clast-supported breccia is characterized by cm-size, angular clasts of the mylonite and is cemented by synkinematic Na-amphibole.

The occurrence of comparable mineral assemblages both along the foliation, in boudin necks, in the veins and in the breccia cement suggests that there is a gradual transition from ductile deformation (folds) to brittle deformation (veining and breccia) passing through a brittle-ductile regime (foliation boudinage) without a substantial change in the overall PT metamorphic conditions (blueschist facies).

All these steps in the deformative history of the mylonite are apparently associated with a strong fluid-rock interaction: the B-mylonite shows an enrichment in incompatible elements (i.e. As and Sb) suggesting an input of fluids, released by the adjacent HP metasedimentary rocks, during ductile deformation. The following fracturing was probably enhanced by brittle instabilities arising from strain and pore-fluid pressure partitioning between adjacent domains with different grain size within the mylonite, without further external fluid input. Ultra-fine-grained domains likely acted as stress risers, focusing brittle deformation; moreover deformation-induced grain size reduction decreased the permeability resulting in an increase in pore fluid-pressure. This promoted the opening of microcracks that in turn generated a fluid-pressure drop, causing disequilibrium conditions at the vein-walls, and the activation of mineralogical reactions; solution transfer to the vein finally induced mineral precipitation and growth.

Fluids were therefore fixed inside the rock during mylonitization and later released into a dense fracture mesh coupled with breccia layers that allowed fluids to migrate through the mylonitic horizon within the subduction zone.

We finally propose that the fracture mesh inside the mylonite might represent the field evidence of past episodic tremors or "slow earthquakes" triggered by high (nearly lithostatic) pore fluid pressure.

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Structural inheritance controlling active crustal deformation in the Val d'Agri area (southern Apennines, Italy): new insights from finite element modelling

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Keywords: Active tectonics, Heat flow density, Frictional heating, Thermal modelling, Temperature profile.

The availability of a large amount of surface geological data and subsurface information gathered by the oil industry, together with seismic and geodetic data, allowed us to define and analyse the active structures in the Val d'Agri area of the southern Apennines. Taking into account that the study of interseismic deformation can be significant to identify locked fault areas that can potentially slip, in this study we present 2D elastoplastic finite-element models to reproduce interseismic characteristics of the study area. This latter hosts the largest Europe's onshore oil field and is characterised by an active extensional tectonic regime, as inferred from earthquake focal mechanisms and fault slip data from late Quaternary structures. Based on high-quality seismic profiles tied with deep well logs, we constructed a detailed geological section across the study area. Outcropping units are dissected by numerous brittle structures that formed at various stages during the tectonic evolution of the Apennines, while the deep ones are dominated by deeply rooted major faults. The rheological behaviour has been constrained by the reconstruction of the thermal structure of the fold and thrust belt, using available information from the foreland Apulian Platform and from temperature data from a series of wells. Starting from an initial model, we reproduced interseismic deformation by means of finite-element numerical modelling, varying boundary conditions and unlocking fault segments. Our numerical models provide new insights into the controversial and widely debated active tectonic setting of the Val d'Agri area, confirming the major role played by structural inheritance and reactivation processes. Long-lived, mature fault systems occurring at depth in the buried Apulian Platform carbonates and underlying basement represent major brittle structures that cumulated displacements of up to a few kilometres over geologic time. As a result of their reactivation within the late Quaternary extensional stress field, these long-lived crustal structures are capable of nucleating strong earthquakes. The decoupling between deep and shallow structural levels, and the different inherited structures affecting them, explain the apparent contrast between the subdued surface expression of active fault systems and the occurrence of large magnitude seismic events in the study area, thus reconciling apparently contrasting geological and geophysical constraints.

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The MATREND experiment: results from laboratory and in situ estimations of thermal properties in borehole heat exchangers

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Keywords: Low enthalpy geothermal resources, heating and cooling building, underground thermal properties.

A multidisciplinary research project aimed at testing materials and technologies for improving the use of renewable energy in the districts of smart city (MATREND) is in progress at the University of Camerino (UNICAM). Among the several tasks, two boreholes, 95 m deep and 9 m apart, were drilled, and heat exchangers (single U type) were installed in view of putting into operation a pilot, low-enthalpy geothermal plant for heating the Geology Division building of UNICAM. This gave a unique opportunity to make a detailed investigation of the underground thermal properties and mechanisms of heat transfer as well as to test the thermal characteristics of the materials used in the implementation of borehole heat exchangers. The experiment consisted of both laboratory and in situ tests. Samples of the main lithotypes encountered during drilling and grouting materials were analysed in the lab for assessing the thermal conductivity. Concerning the grouting materials, the thermal properties of commercial mixtures were analysed. To investigate whether thermal properties can be improved by high-conductivity compounds, grout was doped with alumina. Significant increase of thermal conductivity lambda (30%) was obtained for the mixture with the higher quantity of alumina (40%). The two boreholes were grouted with different mixtures, in order to study the influence of the grout thermal properties on the thermal response of the heat exchangers. The in situ measurements consisted of thermal logs, thermal response tests (TRTs) and monitoring of underground temperatures drop off after the thermal stimulation produced by TRTs. Thermal logs were carried out in the boreholes under conditions of thermal equilibrium for the inference of the thermal gradient and the undisturbed underground temperature. The analysis of the temperature profiles, based on the mass and energy balance in a permeable horizon with uniform thermal and hydraulic properties under steady-state conditions, revealed that the underground thermal regime is dominated by conduction, being the inferred groundwater velocity $< 10^{-6\ m\ s-1}$. TRTs were carried out by injecting in the boreholes a constant heat flow for 60-90 hours. The TRT time series, interpreted according to the classical approach of the infinite line source, gave an overall underground thermal conductivity of 2.2-2.3 W m^{-1} K^{-1}. After the end of TRTs, in both boreholes the temperature drop off has been recorded for one week by means of sensors placed at 20 m depth intervals. On the basis of such data, we tested an approach that allows the inference of thermal conductivity variation with depth. The results indicate that thermal properties are rather uniform in both boreholes and are consistent with those inferred with the infinite line source method.

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Two contrasting fluids in north Sardinia (Italy): geochemical, isotopic and tectonic constraints.

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Keywords: Thermal and cold fluids, geochemistry, helium and carbon isotopes, tectonics, Sardinia.

The Sardinia Island (Italy, western Mediterranean Sea) consists of a portion of Variscan basement, partially covered by sedimentary and volcanic successions, which recorded the significant geodynamic events affecting the southern European margin. From Permian on, this sector of European crust experienced granite emplacement, W-directed subduction of the Ligure-Piemontese Ocean, Tertiary rifting and drifting associated to lithospheric necking. The last tectonic, Pliocene-Pleistocene, event was extensional and is characterized by within-plate basalts extrusion. The Tertiary ENE strike slip faults and NNW to N-S normal faults are the main regional structures of northern Sardinia able to control shallow as well as deep fluid circulation. With this in mind, geochemical investigations were carried out on water and gaseous phases with the two-fold aim of constraining the origin and interactions of the circulating fluids, and to investigate their possible relationships with the tectonic framework. Two main groups of water have been distinguished on the basis of both chemical composition and temperature values. The first group, localized within the an assemblage of NNW trending half-grabens (The so called Sardinia Rifit), consists of cold to hypothermal Na–HCO_3 is characterized by high CO_2 contents and a marked mantle-magmatic He signature. The second group, including hot Na-Cl water outpouring from the crystalline basement, consists of water with high N_2 concentrations and crustal-originated gases. The He mantle signature in the cold-hypotermal fluids within the Tertiary grabens is referable to the Pliocene-Pleistocene mantellic volcanism and, only in a couple of case, to a possible recent seismic activity. The currently active emission of mantle gas decoupled by thermal waters within a trough affected by Tertiary to Quaternary volcanism is the evidence that the heat diffusion process associated to the Pliocene-Pleistocene magmatic activity has already ended in North Sardinia and the mantle gas seepage has outlasted the volcanic thermal perturbation. Conversely, the most reasonable heat source of the thermal (and mantle gas free) water in the basement is the active radiogenic contribute of the thick granitic layer of the Variscan crust.

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Multiparametric modelling of Reservoir Induced Seismicity (RIS): The Pertusillo Lake (Val d'Agri, Italy) case study

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Keywords: Multi parametric model, reservoir induced seismicity, poro-elastic modeling, Val d'Agri.

Reservoir induced seismicity (RIS) is a complex, partially unknown, physical process able to generate small magnitude seismicity up to large magnitude events (e.g., M6.5).

The main mechanism controlling this particular class of seismicity is related to changes of the local stress field and fluid pore pressure caused by the weight of the reservoir impoundment, which can promote earthquake slip on favourably oriented faults. In particular, different factors controlling RIS are: the size of the reservoir; the rapidity and entity of the water-level changes; the presence of pre-existing faults and fractures and their orientation with respect to the local stress field; and the hydromechanical properties and geology of the underlying rocks. As a consequence, in order to develop understanding on RIS, a multidisciplinary approach is strictly required.

Here, we show preliminary results obtained from a multidisciplinary study we are conducting in the Val d'Agri basin (Southern Italy), where a case of RIS associated with rapid changes in the water level of the Pertusillo water reservoir has been documented. The dam, active since 1963, is 95 m height with a maximum reservoir volume of 1.55×10^{8} m^3. Spatiotemporal distribution of seismicity shows a positive correlation with the seasonal fluctuation of the water-level, with microseismicity clustered to the South of the basin, between 2 and 6 km depth, and organized in swarm-like sequences.

Our multidisciplinary approach integrates advanced techniques for the analysis of seismological data (i.e., match-filter technique, 3D Vp and Vp/Vs seismic tomography, high-precision double-difference relative locations, source parameter determination) with the analysis of structural geology, rock physics experiment and subsurface exploration data.

We use these data to build-up an accurate 3D subsurface model of the area in terms of 3D geometry of active structures and mechanical properties of the subsurface lithologies and to establish the relationship between fault structures and the natural/induced seismicity occurring in the southern portion of the Val d'Agri basin. We add information about the present-day crustal strain-rate field, by analysing all available GNSS data spanning the 2000-2016 time-interval to compute 2D strain-rate tensor, and we compare the geodetic strain-rate field with the one derived from seismological observations (e.g. inversion of focal mechanisms for stress tensor parameters).

As last step, we integrate all the information into a multi-parametric model and we compute poroelastic numerical simulations to evalute the effect of water level changes in the Pertusillo reservoir on the stress distribution in the surrounding region and on the favourably oriented faults located to the South of the Val d'Agri basin.

Petrologic modelling of calc-silicate rocks to understand metamorphic-CO_2 processes and fluxes in the Himalayas

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Keywords: Orogenic CO2 cycle, Metamorphic CO2, Calc-silicate rocks, petrology.

Decarbonation reactions during regional metamorphism in “large-hot” collisional orogens are an important source of atmospheric CO_2, able to influence global climate through geologic time (Gaillardet & Galy, 2008). The petrologic study of the CO_2-source rocks (calc-silicates, impure marbles) is therefore fundamental to understand the deep carbon cycle. So far, the incomplete knowledge of these systems hindered a reliable quantitative modeling of metamorphic CO_2 fluxes.

Previous studies aimed at constraining the metamorphic CO_2 flux related to regional metamorphism mainly used simple model reactions between end-members in simple model systems and considered Cal in excess. However, calc-silicate rocks are more complex, because of the occurrence of Ca-Mg-Fe solid solutions (garnet, clinopyroxene), K-(biotite, muscovite, K-feldspar), Ca-Na (plagioclase, scapolite) and Ti-bearing (titanite, biotite) silicates. Moreover, Cal may be completely consumed during prograde metamorphism.

This study aims to define and quantify the CO_2-producing metamorphic reactions that occurred during Himalayan collision using a thermodynamic approach combined with the interpretation of microstructures. Phase relations and devolatilization reactions that occurred in high-grade Cpx + Kfs + Scp + Pl + Zo + Bt + Ttn ± Cal calc-silicate rocks are investigated in the complex NKC(F)MAST-HC system. The equilibria involving plagioclase and scapolite Na-Ca solid solutions, as well as biotite Mg-Ti-(Fe) solid solution are investigated using: (i) P/T-X(CO_2) pseudosections, (ii) P/T-X(CO_2) phase diagram sections and (iii) mixed-volatile P-T phase diagram projections.

We demonstrate that:

(i) the key microstructures correspond to isobaric univariant or invariant assemblages, thus suggesting that the system remained internally buffered during its prograde evolution;

(ii) although challenging and time-consuming, considering complex solid solutions (Na-Ca and Mg-Ti-(Fe)) in the modelling allows to identify CO_2-producing reactions that are otherwise hidden. Particularly relevant is the identification of Ttn-bearing equilibria involving biotite rather than rutile as the Ti-phase counterpart. We demonstrate that, in the studied sample, different Ttn generations grew through Bt-consuming and CO_2-producing reactions. Since titanite is potentially useful as a geochronometer, a detailed knowledge of the equilibria involved in its growth is fundamental for constraining the timing of different episodes of CO_2 production during the Himalayan collision.

(iii) considering Cal in excess might be not correct; the modelling of Cal-poor domains in the studied sample, in fact, highlights that the system is sensible to Cal-absent equilibria.

Gaillardet J. & Galy A. 2008. Himalaya-carbon sink or source? Science, 320**,** 1727-1728.

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Modeling fault reactivation induced by CO_2 underground injection

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Keywords: Induced seismicity, geomechanics, carbon sequestration, numerical modeling.

Overpressure caused by the direct injection of CO_2 into a deep sedimentary system may produce changes in the state of stress, as well as, have an impact on the sealing capabilities of the targeted system. The importance of geomechanics including the potential for reactivating faults associated with large-scale geologic carbon sequestration operations has recently become more widely recognized. In this context, here we review and summarize some recent modeling efforts, aimed at understanding the possible seismicity induced by CO_2 storage and its relation to potential leakage to shallow groundwater aquifer during active injection. The simulations were conducted with TOUGH-FLAC, a simulator for coupled multiphase flow and geomechanical modeling. We carried out both quasi-static and dynamic simulations, with an explicit representation of a fault. In the case of quasi-static modeling, a strain softening Mohr-Coulomb model was used to model a slip-weakening fault slip behavior, enabling modeling of sudden slip that was interpreted as a seismic event, with a moment magnitude evaluated using formulas from seismology. In the case of dynamic modeling, we simulate the fault behavior as strain-softening or rate-dependent, analyzing the frequency behavior at surface and the possible effects of friction properties on slip.

The first part of this work aims at studying the fault responses during carbon dioxide injection, focusing on the short-term (5 years) integrity of the storage repository, and hence on the potential leakage of to shallow groundwater aquifers. We account for stress/strain-dependent permeability and study both the fault reactivation and the leakage through the fault zone. We analyze several scenarios related to the injected amount of CO_2 (and hence related to potential overpressure) involving both minor and major faults, and study induced seismicity and leakage for different stress/strain permeability coupling functions, as well as increasing the complexity of the system in terms of hydromechanical heterogeneities. Our analysis shows that induced seismicity associated with fault reactivation may not necessarily open up a new flow path for leakage. Results show a poor correlation between magnitude and amount of fluid leakage, meaning that a single event is generally not enough to substantially change the permeability along the entire fault length. Furthermore, results show that a thin caprock or aquifer allows smaller events, but a much higher leakage to the upper aquifer. The amount of leakage reduces drastically by assuming a multi-caprock, multi-aquifer system.

Results of dynamic modeling show how the nucleation of fault rupture takes place at the bottom of the injection reservoir. The analysis of the frequency spectrum shows that the seismicity induced by CO_2 injection may produce low damage to ground surface structures and cause nuisance to the exposed population, in the worst-case scenario, and at earthquake epicenter. The analysis of friction behavior shows that a velocity-weakening produces larger ruptures and generates larger magnitude seismic events. Heterogeneous faults have been considered including velocity-weakening or velocity strengthening sections inside and below the aquifer, while upper sections being velocity-neutral. Nucleation of rupture in a velocity strengthening section results in a limited rupture extension, both in terms of maximum slip and rupture length. For a heterogeneous fault with nucleation in a velocity-weakening section, the rupture may propagate into the overlying velocity-neutral section, in cases when the velocity weakening and associated friction drop is large enough.

Finally we compared the previous 2D modeling approach with a more complete 3D formulation. Results show that a well-scaled 2D model well reproduce the 3D modeling results, however with this latter model the analysis can extent to other factor (e.g. injection well direction).

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The role of fluid pressure in fault creep vs. frictional instability: insights from rock deformation experiments on carbonates

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Keywords: friction, induced seismicity, brittle creep, pore pressure.

Fluid overpressure is one of the primary mechanisms for tectonic fault slip. This mechanism is appealing as fluids lubricate the fault and fluid pressure, Pf, reduces the effective normal stress that holds the fault in place. However, current models of earthquake nucleation imply that stable sliding is favored by the increase of pore fluid pressure. Despite this opposite effects, currently, there are only a few studies on the role of fluid pressure under controlled, laboratory conditions. Here, we use laboratory experiments, conducted on a biaxial apparatus within a pressure vessel on limestone fault gouge, to: 1) evaluate the rate- and state- friction parameters as the pore fluid pressure is increased from hydrostatic to near lithostatic values and 2) fault creep evolution as a function of a step increase in fluid pressure. In this second suite of experiments we reached 85% of the maximum shear strength and than in load control we induced fault slip by increasing fluid pressure. Our data show that the friction rate parameter (a-b) evolves from slightly velocity strengthening to velocity neutral behaviour and the critical slip distance, Dc, decreases from about 100 to 20 μm as the pore fluid pressure is increased. Fault creep is slow (i.e 0.001μm/s) away from the maximum shear strength and for small increases in fluid pressure and it accelerates near the maximum shear strength and for larger fluid pressure build-ups, where we observe episodic accelerations/decelerations that in some cases evolve to small dynamic events. Our data suggest that fluid overpressure can increase aseismic creep with the development of frictional instability. Since fault rheology and fault stability parameters change with fluid pressure, we suggest that a comprehensive characterization of these parameters is fundamental for better assessing the role of fluid pressure in natural and human induced earthquakes.

Origin and role of fluids involved in the seismic cycle of extensional faults in carbonate rocks

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Keywords: fluid circulation, seismic cycle, fluid pressure, stable isotopes, fault zone evolution.

We develop a conceptual evolutionary model with structural and geochemical methods that examine the seismically-active extensional Tre Monti Fault (central Apennines, Italy) of seismic faulting with fluid involvement in shallow (≤ 3 km depth) extensional faults in carbonate rocks. Multiscale fault rock structures include injection veins, fluidized ultracataclasite layers, and crackle breccias suggesting that the fault slipped seismically. The relative chronology of these structures was reconstructed through establishing the cross-cutting relationships and cathodoluminescence analyses. We use C- and O-isotope data from different generations of fault-related mineralizations show a shift from marine- to meteoric-derived fluid circulation during exhumation from 3 to ≤1 km depths and concurrent fluid cooling from ~68 to <35 °C. Between ~3 km and ~1 km depths, impermeable barriers within the sedimentary sequence created a semi-closed hydrological system, where marine-derived fluids circulated within the fault zone at temperatures between 60° and 75°C without any mixing with meteoric-derived fluids. During fault zone exhumation at depths ≤ 1 km and temperatures <35 °C, the hydrological circulation became open and meteoric-derived fluids progressively infiltrated and circulated within the fault zone. The role of these fluids during syn-exhumation seismic cycles of the Tre Monti Fault has been substantially passive along the whole fault zone, with the fluids being passively redistributed at hydrostatic pressure following co-seismic dilatancy. Only the principal fault has been characterized, locally and transiently, by fluid overpressures. The presence of low-permeability clayey layers in the sedimentary sequence contributed to control the type of fluids infiltrating into the fault zone and possibly their transient overpressures. These results can foster the comprehension of seismic faulting at shallow depths in carbonate rocks of other fold-thrust belts involved in post-collisional seismogenic extensional tectonics.

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Fluid injection in Enhanced Geothermal Systems: a study on the detectability of self-potential effects and on their correlation with induced seismicity

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Keywords: Enhanced Geothermal Systems, Fluid injection, self-potential (SP) anomalies, induced seismicity.

We present a numerical modeling aimed at investigating nature and role of the self-potential (SP) anomalies induced by water injection in boreholes at the Soultz-sous-Forêts (SsF) hot dry rock enhanced geothermal field. The overpressure due to the fluid stimulation is considered as source of the streaming potential effects in rocks, responsible on their turn of the SP anomalies observed at the ground surface. The numerical simulations have been realized by a combined application of the TOUGH2 and Comsol Multiphysics codes, which had already been successfully used to predict Coulomb stress changes in rocks induced by a fluid injection cycle. Two synthetic cases are investigated. At first, a simulated injection cycle in a single borehole has been modeled, consisting in the reconstruction of the overpressure and SP temporal and spatial evolutions induced by the hydraulic stimulation of the rock. The main result is that the front of the SP anomaly follows the overpressure front, with the time delay between the two fronts decreasing at increasing distance from the well. The second case takes into consideration a real injection experiment performed in 2003 at SsF, which has allowed to examine the induced seismicity. The simulated SP response to this real injection cycle shows that the SP temporal evolution is essentially a post-seismic effect. The conclusion from the simulations is that SP measurements can be used to localize the main features of the fluid flow into the reservoir.

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Geological structures, HT-fluids flow and permeability in the exhumed geothermal system of Eastern Elba Island (Italy): the case of Cala Stagnone

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Keywords: Structural geology, Geothermal systems, Fluid inclusions, Elba Island.

This work illustrates the results of a study focused on the relationships between brittle structures and mesothermal mineralizations exposed at Cala Stagnone where a low-P metamorphic basement affected by advective heat transfer crops out. This is made up of crd+and micaschist intruded by granitic dykes and both crosscut by different generations of fine-grained tourmaline (schorl-dravite and/or uvite) and quartz veins, also ascribed to hydrofracturing events.

This framework accounts for an evolution deriving from the emplacement and cooling of the Porto Azzurro monzogranite (5.9 Ma), thus defining an exhumed geothermal system that can be considered as an analogue of the presently exploited Larderello geothermal field.

A simple field-based methodology was applied in order to get: i) structural and kinematic data by means of detailed structural maps (1:100 scale), scan lines and scan boxes (40x40 cm^2); ii) within each box, length, width and frequency of each generation of mineralized shear veins were recorded and analysed to estimate permeability, adapting existing algorithms to the study case; iii) collection of samples for fluid inclusions (FIs) analyses in order to get information on parent fluids (i.e. composition and entrapping paleo-temperatures).

The estimated permeability values are in the range between 10^{-12} and 10^{-18} m^2, with a maximum distribution of data around 10^{-14} m^2 and these are comparable with those measured in the Larderello boreholes.

Regarding FIs, analyses have been carried out mainly in quartz of the quartz-tourmaline veins, and rarely in tourmaline. In quartz, two main types of inclusions have been found: i) S-type hypersaline FIs, (29-49 wt.% NaCl eq.) with moderate total Th (<400°C); and ii) L- and V-type FIs with lower salinity values (16-30 wt.% NaCl eq.) and with moderate to high Th (up to 600°C). In tourmaline, FIs are only of L-type and the few Th data are <415°C. Isochores were calculated using data for the H_2O-NaCl system to derive trapping P-T conditions of the fluid. Data suggest that high temperature L inclusions have exsolved directly from crystallizing magma at moderate pressure; pressure fluctuation, possibly related to hydrofracturing, shifted fluid density below and above critical isochore, producing the typical assemblage of V- and L-type FIs. Estimated trapping pressure and temperature are: 800<Pmax<1600 bars and 550<Tmax<650°C. Sealing of the system resulted in increasing pressure (up to 2000 bars) and salinity of the fluid, corresponding to the stage when S-type FIs were formed.

Variation of the type of total homogenization of these inclusions could be also related to pressure variations as consequence of hydrofracturing.

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SESSION S5

Localization of deformation in the lithosphere: from brittle faults to ductile shear zones

CONVENERS AND CHAIRPERSONS

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Localization of brittle/cataclastic deformation along extremely weak and anisotropic mylonites the Simplon Line (Western Alps)

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Keywords: Simplon Line, weak fault localization.

The Simplon Fault Zone is a late-collisional low-angle normal fault (LANF) of the Western Alps. The hanging wall shows evidence of brittle deformation only, while the footwall is characterized by a c. 1 km thick shear zone (the Simplon Fault Zone), which continuously evolved, during exhumation and cooling, from amphibolite facies conditions to brittle-cataclastic deformations. Due to progressive localization of the active section of the shear zone, the thermal-rheological evolution of the footwall resulted in a layered structure, with higher temperature mylonites preserved at the periphery of the shear zone, and cataclasites occurring at the core (indicated as the Simplon Line). In order to investigate the weakness of the Simplon Line, we studied the evolution of brittle/cataclastic fault rocks, from nucleation to the most mature ones. Cataclasites are superposed on greenschist facies mylonites, and their nucleation can be studied at the periphery of the brittle fau lt zone. This is characterized by fractures, micro-faults and foliated ultracataclasite seams that develop along the mylonitic SCC' fabric, exploiting the weak phases mainly represented by muscovite and chlorite. Approaching the fault core, both the thickness and frequency of cataclasite horizons increase, and, as their thickness increases, they become less and less foliated. The fault core itself is represented by a thicker non-foliated cataclasite horizon. No Andersonian faults or fractures can be found in the footwall damage zone and core zone, whilst they are present in the hanging wall and in the footwall further from the fault. Applying a stress model based on slip tendency, we have been able to calculate that the friction coefficient of the Simplon Line cataclasites was <0.25, hence this fault zone is absolutely weak. In contrast with other fault zones, the weakening effect of fluids was of secondary importance, since they accessed the fault zone only after an interconnected fracture network developed exploiting the cataclasite network.

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Structural Geology and Active Tectonics of the Great Geneva Basin (Switzerland and France)

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Keywords: Jura, fold-and-thrust belt, Alps, active tectonics, fault system, fluid flow.

The Canton of Geneva (Switzerland) is exploring the opportunity to exploit geothermal energy in the Great Geneva Basin (GGB). This requires a clear understanding of the recent and present tectonic regimes affecting the area. The goal of this study is to describe the ongoing tectonic deformation and to assess preferential paths for fluid flow in the sedimentary cover.

The GGB, is a Tertiary piggyback basin tightened between the Alps and the southern Jura fold-and-thrust belt. The GGB was built during the sedimentation of the Oligo-Miocene marine-continental siliciclastic Molasse formations. The Molasse deposited onto deforming Mesozoic carbonate thrust sheets crossed by tranversal faults of different orientation and size.

Here we propose a review of the regional tectonic to i) characterize fault systems, ii) identify neo-tectonic deformation evidences, and iii) identify regions of preferred fluid flow. Faults are organised in a series of transversal and thrust structures (i.e. transpressional regime).

Preliminary data highlight the occurrence of two main transversal fault sets. The first-one strikes NNW-SSE and it is constituted by tear faults with fault length up to 60 km in map view. It cuts the whole Mesozoic-Cenozoic cover, and possibly also the Quaternary deposits (i.e., Vuache fault). Such fault system causes shallow (i.e. less than 10 km depth) earthquakes reaching local a magnitude as high as M_L 5.3 (i.e., Epagny earthquake in 1996). This suggests that active faults may reach the deeper parts of the detached sedimentary cover. Yet, it is still debated whether active faulting still occurs in the crystalline basement. The second set is constituted by up to 10 km long tear-faults confined at the upper thrust sheets and limited at the Meso-Cenozoic formations. By cross-checking the 2D seismic lines, we track the continuity of some of them up to the surface. Finally, field data show that fault fabric is locally affected by veins in carbonates. Those are organized in different sets possibly related to the variations of the stress regime through time, thus implying tectonic conditions that may favour or hinder fluid flow.

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A composite strike-slip model for the Corsica-Sardinia Batholith (France-Italy)

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Keywords: Corsica-Sardinia Batholith, Variscan, Shear Zones, Strike-Slip.

The Corsica-Sardinia Batholith (C-SB) is a large magmatic province developed along the southern margin of the Variscan chain during post-collisional extension. Most of the batholith consists of U2 calc-alkaline plutons emplaced episodically during the Carboniferous-Permian (320 – 290 Ma) transition. The composition of U2 melts is quite heterogeneous ranging from that of typical crustal granites (U2c), i.e., A.S.I. > 1.12, eNd_t < -5, Sr_i > 0.715, absence of micro-granular mafic enclaves, to that of hybrid rocks with a clear mantle component (U2m).

High-resolution U-Pb zircon dating revealed two major clusters of ages that reflect activation of different crustal structures during the emplacement of U2 plutons. The first melts (U2c, 320-310 Ma) emplaced within a network of NW-SE to NNW-SSE dextral transpressional structures bridging adjacent E-W sinistral transtensional shear zones injected by U2m (315 – 300 Ma) plutons. The network of shear zone activated in response to NNW-SSE shortening, in present-day coordinates, which is consistent with the mean Variscan s_1. This simple kinematic model accounts for the discrepancies between different calc-alkaline plutons, as NW-SE plutons with distinctive crustal character fit transpressional structures where shear heating, and thus crustal melting, is expected to be maximum and the pressure gradient is unfavorable for mantle melt to raise. On the other hand, E-W sinistral transtensional zones might have acted as easy way up for the mantle-derived melts produced during the general decompression of the Variscan crust. Crustal-scale strike-slip shearing allows to explain in a self-consistent model the peculiar isotopic and geochemical features of melts, the pluton's geometry, their emplacement mechanism, and the episodic construction recorded by the C-SB overall.

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Association of brittle and ductile deformation structures within the Rieserferner granitoid pluton (Eastern Alps)

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Keywords: Rieserferner, shear zone, joint, granitoid folding.

The Oligocene tonalitic-granodioritic Rieserferner pluton emplaced at a depth of 12-15 km (Cesare, 1994) within the Austroalpine domain of the Eastern Alps. During pluton cooling and exhumation a series of solid-state ductile shear zones and brittle faults developed in the intrusive rocks. The nucleation, geometry and orientation of these deformation structures was controlled by the presence of 3 main sets of earlier brittle joints.

A set of joints is steeply dipping and strikes WNW-ESE; these joints were reactivated as strike-slip ductile shear zones (as indicated by marker offsets and by the geometry of foliated contractional jogs at joint stepovers) and filled with quartz veins in extensional bends.

A set of joints is shallowly dipping towards E; these joints are commonly filled with quartz and/or epidote veins, and were exploited as ductile shear zones showing a top-to-east (extensional) sense of shear. These quartz veins sharply localized ductile shear and were commonly transformed to quartz mylonites. Epidote-filled veins acted as nucleation structures for heterogeneous shear zones involving the host tonalites.

A set of steeply dipping and N-S striking joints were exploited by transtensive brittle-ductile faults. Faulting was associated with extensive fluid infiltration. The set of spatially dense sub-parallel fractures linked to these faults promoted the development of meter-scale flexural-slip folds in granitoids.

As reported from other plutons (e.g. Adamello: Pennacchioni, 2005; Sierra Nevada: Pennacchioni and Zucchi, 2013) and meta-granitoid units (Pennacchioni & Mancktelow, 2007), the ductile shear zones of the Rieserferner localized on brittle precursors (joints) and compositional heterogeneities (quartz and epidote veins). In contrast, the numerous mafic and felsic dikes did not localized ductile strain. Ductile folding associated with faulting is interpreted to have resulted from fluid-assisted deformation associated with the presence of a pervasive set of fractures.

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Shallow earthquakes: are they "brittle" or "ductile"?

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Keywords: faults, earthquakes, friction, carbonates, melting, superplasticity, graphitization.

Shallow regular earthquakes (hypocentral depth < 25 km) are considered the most typical expression of the "brittle" behavior of the Earth crust. They usually originate on preexisting faults and occur because faults weaken with increasing slip and slip rate. It follows that the "frictional" evolution of fault materials is of paramount importance in controlling the seismic rupture and slippage. Because of the large stresses (hundreds of MPa at >10 km depth) and slip rates (about 1 ms^{-1}) involved, a large amount of frictional work rate (product of frictional shear stress per slip rate) is dissipated along faults during earthquakes. The frictional work rate can be so large (1 to 100 MW m^{-2}) as to grind and mill the rock down to nanometric size and induce large temperature increase in the slipping zone (up to 2000 °C). Under these extreme deformation conditions, the fault surfaces are separated by fluids or other tribochemical products (crystalline or amorphous nano-powders; dehydration and decarbonation products; gels; melts). It follows that earthquake physics is controlled by the mineral reactions and phase changes triggered by the passage of the seismic rupture and, as a consequence, by the rheology of the newly formed products.

Here, by exploiting the results of (1) field and microanalytical studies conducted on natural fault products, and (2) experimental studies reproducing the extreme deformation conditions typical of seismic slip, we will discuss the mineral reactions, the phase changes and the grain size-dependent processes concomitant to and possibly responsible for fault weakening during earthquakes. We conclude that during earthquake rupture propagation, seismic slip is controlled by temperature-dependent processes in some cases thought to be typical of the so-called "ductile" deep crust.

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The role of pseudotachylytes during strain localization in the lower crust (Musgrave Ranges, Central Australia)

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Keywords: localization, lower crust, pseudotachylytes, brittle, ductile, Australia.

Tectonic pseudotachylytes develop by friction-induced melting during seismic slip along a fault. Pseudotachylyte form fine grained veins that both decorate the slip surface (generation surface) and intrude the host rock (injection veins). The generation surface represents a nearly planar discontinuity that can be continuous over hundreds of meters and provides an ideal precursor for localizing ductile shear during post seismic creep.

The Musgrave Ranges, in Central Australia, provide a unique insight into lower crustal deformation thanks to the lack of vegetation and the continuity of outcrops. During the Petermann Orogeny (550 Ma), the about 5 km wide Davenport Shear Zone accommodated strike-slip movement in the hanging wall of the Woodroffe Thrust. All larger structures in this area are associated with abundant pseudotachylyte, which may or may not be subsequently ductiley sheared and thereby foliated. Low strain domains within the mylonite zone are ideal to study the initial localization of deformation. In these areas, ultramylonitic shear zones within meta-granitoids are sharply bounded and only a few millimeters wide, but extend for several tens to hundreds of meters. On a microscopic scale, these ultramylonites show ribbons of quartz within a matrix of micron-sized clinopyroxene, garnet, feldspar, and sometimes kyanite. Metamorphic conditions are estimated to be around 650 °C and 1.2 GPa from quantified WDS-maps combined with conventional geothermobarometry. Injection vein geometries are locally preserved and, in some cases, breccias are evident from a sinusoidal foliation network encompassing rotated clasts of the host rock. These observations clearly indicate that the precursor of the shear zones was pseudotachylyte. Furthermore, sheared pseudotachylyte is sometimes observed as clasts within a younger generation of pseudotachylyte, which is itself subsequently sheared. We interpret these structures to represent cycles of brittle fracturing during seismic rupture followed by ductile overprint during post seismic creep.

In contrast, quartz veins, pegmatites and mafic enclaves parallel to these localized shear zones exploiting pseudotachylytes did not localize deformation. We therefore propose that for lower crustal deformation, brittle precursors, rather than isolated compositional heterogeneity, play the major role in localizing deformation.

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The Compione Fault: damage zone structural and paleofluid characterization of a segment of the Lunigiana extensional fault systems, Northern Apennines

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Keywords: Extensional fault, fault damage zone, vein, microthermometry, stable isotopes.

The Compione Fault is a segment of the basin boundary extensional fault system in the Lunigiana region, Northern Apennines, Italy. Stratigraphic evidence indicates that extension in the area is active since Early Pliocene times. Recent seismicity provides further support to present-day fault activity, clearly indicated by its geomorphic signature. The Lunigiana fault system in its eastern branch is composed of three main fault segments, striking almost NW-SE and dipping 60-70˚ to the SW. The stratigraphic separation of the Compione Fault exceeds 1 km and caused the tectonic juxtaposition of turbiditic sandstones of the Late Oligocene-Early Miocene Macigno Fm. in the footwall, against the calcareous pelites, siltites and fine sandstones of the Ottone Fm. (a Late Cretaceous Helminthoid Flysch) in the hangingwall. The Compione Fault overprints the previously-formed contractional tectonic stack where the Ottone Fm. overthrusted the Macigno Fm. during Miocene times. We performed a detailed structural analysis along a representative cross-section perpendicular to the Compione Fault in its central part, particularly focussing on the quantitative characterization of the damage zones. Field work was coupled with laboratory analyses including standard and cold cathodoluminescence petrography, and microtermometric and stable isotope analysis of vein cements. Field data show that in the footwall, extensional deformation affecting very thick and coarse sandstone strata caused intense fracturing, mostly by low displacement conjugate extensional faulting. Hangingwall rocks are less fractured than footwall rocks due to their different composition and rheology, which favoured abundant dissolution-cementation processes and extensional faulting along less numerous, higher displacement synthetic and antithetic shear zones. Footwall vein infill includes clinozoisite, quartz and calcite, while hanging wall veins are cemented by only calcite. Microtermometric analysis reveals an exhumation trend in footwall rock cements, characterized by biphase acqueous fluid inclusions, which hold homogenization temperatures spanning from more than 200 °C to 70 °C, and by methane fluid inclusions. In hanging wall rock cements, fluid inclusions were trapped in low temperature conditions from low salinity fluids. We propose an evolutionary model of the Compione Fault starting with upward propagation as a blind extensional fault zone dissecting the previously formed thrust-related nappe stack. Intense fracturing in the footwall sandstones occurred in the very early fault propagation stages. With increasing displacement, extensional fault-propagation folding caused passive rotation of both footwall and hangingwall rocks and associated, previously-formed fracture patterns, up to 50-60˚ to the SW. Eventually, fault breakthrough caused deformation localization within a thick cataclastic fault core.

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Quantification and modeling of shear heating as tool to reconstruct the thermo-mechanical history of a brittle-ductile fault

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Keywords: brittle-ductile fault, shear heating, numerical modeling, thermochronometry, fluid inclusion.

The role of each mechanism able to convert mechanical energy into heat - rock fracturing and pulverization, frictional sliding, crystal-plastic deformation - is well known but few geological evidences support the physical effectiveness of shear heating. Moreover, several more traceable mechanisms can generate fault zone heating, including advection or upwelling of hot fluids. The difficulty in recognizing the thermal effect of mechanical work often leads to an underestimation, or even total neglect, of the contribution of shear heating to the thermal budget.

However, the shear-heating signal could supply fundamental information about the evolution of the fault and its mode of failure. For example, brittle faults characterized by highly localized deformation, are thought to record elevated temperature change between the core and the wall rocks, particularly during large slip displacement earthquakes. However, apart the occasional recognition of pseudotachylites, faults generally show poor evidences of frictional heat because of weakening mechanisms. Furthermore, significant temperature rises into fault zone characterized by distributed deformation have been identified in many major fault zones but their relationship with shear heating is controversial.

Several indicators of high- to low-T temperature change within the fault zone with respect the wall rocks can be applied (e.g. vitrinite reflectance and Raman spectra of carbonaceous material, organic thermal maturity, thermal decomposition of carbonate, magnetic analyses, magnetite formation from siderite, smectite to chlorite conversion, stretching of fluid inclusions in calcite, etc) but they can estimate – even with large uncertainties - only proxy temperatures possibly occurring during either flash or long-term heating associated with high-velocity friction or creeping.

We present a research that couples field and microstructural observations, clay mineralogy (illite, chlorite), microthermometry of fluid inclusion trapped in quartz and calcite veins and zircon (U-Th)/He thermochronometry to recognized the mechanical origin of the measured temperature rise and synthesize the observed thermal patterns into a fully coupled thermo-mechanical 1D model of a fault zone. The measured thermal parameters allows to modeling the mechanical behavior of the fault (multiple high-velocity events vs. continuous creeping) on the geological time-scale.

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Brittle-viscous rheological cycles in the dry and strong continental lower crust

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Keywords: brittle deformation, ductile deformation, shear zones, crustal rheology, microstructure, deformat

Many rheological models of the lithosphere predict a weak aseismic lower crust below the strong brittle upper crust. An alternative view, based on the distribution of crustal seismicity, is that the lower crust could also be strong and seismic. It has been suggested that a strong, seismogenic lower crust results from the dry conditions of granulite facies rocks, which inhibit crystal plastic flow. Given that large parts of the lower crust consist of granulites, investigating deformation processes and strain localization in these rocks is a major goal of structural geology and tectonics, the results will provide insights to the earthquake distribution and cycle and to large-scale lithosphere dynamics.

This study investigates exhumed networks of shear zones from Nusfjord (Lofoten, Norway) to understand initiation and localization of viscous shearing in the dry and strong lower crust. In the study area, different sets of ultramylonitic shear zones are hosted in massive granulitic anorthosites. Field evidence indicates that ductile shearing exploited pseudotachylyte veins (solidified frictional melt produced during coseismic slip) and the associated damage zone of fracturing. Field- and thin section observations indicate that frictional melting occurred at the same deep crustal conditions of mylonitization, which were estimated at 650-750 °C, 0.7-0.9 GPa using thermodynamic modelling of mineral equilibria. Mutually overprinting pseudotachylytes and mylonites indicate brittle-viscous deformation cycles, and possibly represent the geological record of the transition from coseismic slip to postseismic creep in the lower crust.

Detailed microstructural (EBSD) analysis of the ultramylonites suggests that diffusion creep and grain boundary sliding were the main deformation mechanisms. The metamorphic assemblage in the mylonitized pseudotachylytes requires ca. 0.4 wt% of water, indicating that brittle deformation triggered fluid infiltration in otherwise dry anorthosites. Accordingly, nucleation of hornblende in dilatant sites indicates that fluids were channelized in the ultramylonites. The infiltrated aqueous fluid assisted grain boundary diffusion and nucleation of fine-grained hydrated phases, resulting in phase mixing and strain localization in the ultramylonites deforming by grain size sensitive creep.

In summary, this study indicates that brittle (coseismic) fracturing was essential to weaken the dry and strong lower crust by activating grain size sensitive creep in the fine-grained hydrated material resulting from grain size reduction. Coseismic fracturing resulted in the ductile shear zones localized to the brittle precursors. In the absence of intense fracturing dry granulites would not undergo deformation and metamorphism, and would survive metastably in the course of Wilson cycles. This has obvious implications for long-term continental dynamics and for strain localization at plate boundaries, and will need to be included in future geodynamic models.

The evolution of fabric with displacement in natural brittle faults

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Keywords: faults, microstructures, localization.

Faults in the seismogenic crust are often decorated by a layer of granular material, whose mechanical properties are controlled by mineral composition and fabric. Both evolve during fault activity, due to mechanical (grain comminution and abrasion) and chemical (mineral breakdown, mass transfer, fracture sealing and healing) processes. We evaluated the effects of increasing shear strain on the fabric of small displacement faults in an ancient seismogenic fault zone hosted in tonalite and active at 9-11 km depth, typical earthquake nucleation depth in the continental crust. The samples were stem from cohesive cataclasites, associated or not with pseudotachylytes, with cumulative slip of 0 – 4.7 m and finite strain from 0 to 296. Sample microstructure was analyzed by means of quantitative microstructural measurements, Scanning Electron Microscope (SEM) Back Scatter Electron imaging and Energy Dispersive X-Ray Spectroscopy (EDS) equipped SEM for chemical mapping.

Cataclasites are composed of clasts of plagioclase and quartz, derived from crushing of the host tonalite, and cemented mainly by epidote, chlorite and K-feldspar. For grain sizes between 5 and 30 μm, the two dimensional clast size cumulative distribution is fitted with a power-law relation. From studies of natural and experimental cataclasites (e.g., Sammis et al., 1987; Marone & Scholz, 1989), it is known that the slope D of the clast size distribution in a log-log plot increases with increasing shear strain. In our samples, with increasing finite strain: (i) the average clast size decreases (ii) the slope D of the bulk clast size distribution increases from 1.2 to 2.0 (iii) multiple microstructural domains develop. Layers of highly comminuted, high D (up to 2.8) cataclasite are found for bulk finite strains higher than 82. Coarser and less evolved cataclasites show evidence for stress driven mineral reactions, with incipient mineral segregation (epidote in sites of dissolution, K-feldspar in sites of precipitation) and preferential dissolution of quartz clasts compared with plagioclase.

The development of a layer of fine grained, evolved material is associated with strain localization, and possibly strain weakening behavior. Coarse grained cataclasites are proportionally thicker and affected by diffuse stress driven fluid-rock interactions, suggestive of strain hardening behavior.

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Switching deformation mode and mechanisms during natural faulting of Carrara marble

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Keywords: Fault, Carrara marble, Deformation mechanisms, Deformation mode.

A study of meso- and microstructural features of an exhumed high angle normal fault observed in Carrara marble of the Alpi Apuane NW Tuscany (Italy) is here presented. The studied fault was formed at shallow crustal depth and related with the recent deformation history of the Alpi Apuane metamorphic core (Molli et al. 2015, Molli et al., 2016). On the basis of meso- and microscale deformation features different stages of fault zone evolution were recognized. Stage 1 was associated with extensional and shear veins now observable in both hangingwall and footwall blocks as part of the deformation zone developed at decameter-scale. Geochemical data indicate vein-development in a locally closed system where a "stationary" fluid phase migrates over meter-scale distances (Molli et al., 2011). At stage 2, a localization of the deformation took place. During this second stage, crystal-plastic deformation affected a millimeter-thick zone along the main slip surfaces, whereas cataclastic deformation produced a decimeter to meter thick fault core with brecciation and far-derived fluid channelling leading to significant geochemical alteration of the fault rocks with respect to the protolith (Molli et al. 2011). Deformation was then localized within ultracataclasite of the fault core where diffusive-mass transfer dominates the microstructural development (stage 3). The fault history ends with stage 4, associated with a vertical shortening and development of slickolites at the contact between the main slip surface and fault core and microveins plus stylolites within the fault core.

The analysis of the studied fault within Carrara marble reveals therefore a switching in the deformation mode in terms of distributed vs localized and a changing in deformation mechanisms; these features may be associated, following the most recent experimental work (e.g. Smith et al., 2012), with a "fossil" seismic cycle.

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Thermal and kinematic evolution of a regional detachment: insight from the South Tibetan Detachment (Tibet, Himalaya)

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Keywords: South Tibetan Detachment System, ductile- brittle shear zone, non-coaxial deformation, Himalaya.

The South Tibetan Detachment System (STDS) is well known since the eighties. Till now the research has been mainly focused on the geometry and kinematic of the lower ductile and the upper brittle faults and on the deformation of the footwall rocks, i.e. high-grade metamorphic rocks belonging to the Greater Himalayan Sequence (GHS).

In this study we mainly focus on the hanging wall rocks belonging to the Tethyan Sedimentary Sequence (TSS). We sampled a 1,5 km thick section of the TSS made up by Paleozoic sequence cropping out above the STDS in Dinggye area (South Tibet).

The Ordovician limestone, at the bottom of the unit, is characterized by a ductile heterogeneous deformation during which calcmylonites were developed. Centimetric to decimetric high-strain zones, post-dating D1 distinct isoclinal folds, are associated to a mylonitic foliation striking parallel to the STDS and dipping few degrees to the North. Kinematic indicators like asymmetric strain fringes around pyrite crystals and polycristalline calcite or calcite/dolomite aggregates, foliation boudinage and asymmetric boudinage of calcite veins confirm a top-to-the NE sense of shear.

Microfabric analysis of calcite reveals shape and lattice preferred orientations as well as grain size reduction within layers of cm-thickness indicating intracrystalline slip and dynamic recrystallisation as the main deformation mechanisms.

Moving upward in the sequence, primary sedimentary structures are still well recognizable and there is a sharp transition to very-low grade deformation mechanism where pressure solution is predominant.

A strain increase has been detected along the section moving from top to bottom. While deformation temperatures have been constrained at 350°C by calcite-dolomite geothermometer for Ordovician calcmylonites at the bottom of the TSS, a change of syntectonic twinning in calcite crystals pointed out a decreasing deformation temperature of about 150°C moving from the bottom to the top of the section.

Dominance of magnetic remanence unblocking at the Curie temperature of pyrrhotite supports peak metamorphic temperatures of at least 325°C for samples coming from the bottom of the sequence.

Vorticity kinematic numbers (Wk) have been derived from lattice preferred orientations (LPOs) of calcite, which were determined by means of an X-ray goniometer on suitable samples. Wk highlighted an equal contribution of pure and simple shear components during deformation.

The estimated deformation temperatures point out a high apparent field thermal gradient for the study section of about 100°C/km. Two main facts can be responsible: 1) strong vertical shortening due to a combination of pure and simple shear components during deformation; 2) heating effect linked to the exhuming high-grade hot rock of the underlying GHS coupling with the colder TSS rocks.

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Ductile-brittle transition at very shallow crustal level: role of thermal anomaly and fluid circulation investigated from field and microstructural data (Eastern Elba Island, Italy)

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Keywords: Ductile-brittle transition, structural analysis, progressive deformation analysis, microstructure.

In Eastern Elba Island the Oligo-Miocene nappe stackof the Northern Apennines was intruded by the Porto Azzurro pluton (6.3 – 5.9 Ma) at upper crustal level (40Ar/^{39}Ar dating of synkinematic muscovite and phlogopite in the shear zones constrained deformation between 6.76±0.08 Ma and 6.23±0.06 Ma (Musumeci et al., 2015 and references therein). The aim of this work was to investigate the extent of deformation and the structural evolution of the aureole, combining detailed structural analysis and field mapping with microstructural observations. The main foliation within the aureole is directed NS and it is associated with E-W striking aggregate and mineral lineations. Localized 0.1-2.0 m. thick mylonitic bands bound 10 to 100 m thick relatively low strain domains, displaying tight to isoclinal folds. Shear zones recorded the switch from ductile to brittle conditions as a cataclastic overprint over the mylonitic fabric which was associated with a constant top-to-NE sense of shear. The brittle fabric is characterized by fault breccias associated with ore bodies and metasomatic rocks, suggesting that fault zones acted as a preferred path for deep fluid migration and that fluids played a role on fault localization. The parallelism and structural continuity between LT mylonites and cataclasites suggests a continuum of deformation beyond the brittle/ductile transition resulting from the vanishing thermal pulse.

Quartz microfabric in mylonites recorded the evolution from GBM down to SGR and BLG dynamic recrystallization mechanisms prior to the cataclastic overprint, indicating progressive temperature drop during deformation. These preliminary data suggest a microstructural control over the quartz microfabric, which can be explained as a result of: 1) increasing strain partitioning during cooling; 2) presence of high strain rate subdomains; 3) modifications of fluid availability and composition over time.

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Fluid-mediated brittle-ductile cyclicity in quartz veins from brittle fault zones (Onkalo, SW Finland)

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Keywords: quartz veins, brittle fault zones, Finland.

Brittle faults archive details of physical-chemical conditions during initial localization and reactivation. Crustal deformation at the brittle-ductile transition is being increasingly shown to accommodate competing cracking and viscous flow, with short-lived variations in fluid pressure as a viable mechanism to trigger cyclicity between these two end-members. The deformation style reflects the dynamic interplay between weakening and hardening mechanisms, themselves function of processes such as friction, fluid flow and rheological changes within dilatant rock volumes. Further complexities reflect the often underestimated dynamic nature of faults, whose internal architecture, composition and rheological properties evolve through time and space. Aiming to 1) better understand the complexities of brittle-ductile cyclicity in crustal conditions, 2) determine the characteristics and properties of the involved fluids, 3) generate a multi-scale reference dataset to predict the dynamic evolution of crustal strength within the seismogenic zone, we present a structural and geochemical dataset on deformed quartz veins associated with brittle deformation zones in Onkalo, the Finnish deep repository for spent nuclear fuel excavated in the Paleoproterozoic crust of southwestern Finland. Brittle fault zone BFZ300 contains two sets of up to 150 mm thick quartz veins (Qtz1 and Qtz2), which were emplaced at different times within- and parallel to the strike of the c. 1.5 m wide fault. BFZ300 defines an overall hybrid dextral strike-slip system, which contains also sinistral and pure dilational fractures. A rotation of the greatest horizontal compressive axis between the emplacement of Qtz1 and Qtz2 caused partial reactivation of the Qtz1-decorated first dilational and hybrid fractures and renewed dilation, promoting crystallization of Qtz2 veins, subparallel to Qtz1. EBSD analysis supports cyclic switches between brittle and viscous deformation. Qtz1 recrystallized along grain boundaries and intracrystalline bands, with scarce recovery. Low-angle boundaries are rarely associated with subgrains, but rather with micro-cracks parallel to the traces of prism and basal planes and to fluid inclusion trails. Recrystallization preferentially occurred along micro-cracks and exploited the associated micro-gouges. Micro-cracks possibly formed during emplacement of Qtz2, which is coarse grained, contains only limited evidence for viscous deformation and is in turn affected by later microfracturing. Preliminary fluid inclusion data show that, during crystallization and brittle-viscous deformation, Qtz 1 and Qtz 2 hosted homogeneous and heterogeneous (boiling) aqueous fluids with a large salinity (11.7-0 wt% $NaCl_{eq}$) and T_{htot} (410-200 °C) range. Boiling occurred at 200-260 °C. Variations of fluid temperature and density (hence, viscosity) may thus have induced cyclic switches between brittle and ductile deformation in quartz, with implications on crustal strength.

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A method to analyze the incremental strain in heterogeneous shear zones

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Keywords: shear zone, strain softening, finite strain, incremental strain, inverse method.

An inverse method is proposed (Vitale and Mazzoli, 2015), which is able to provide the incremental strain path in heterogeneous ductile shear zones based on the measured values of finite strain quantities. The technique is based on the assumption that each part of a heterogeneous shear zone is the result of a different strain evolution, and taken all together the various parts of a shear zone are able to record the whole strain history. Application of the proposed method to two ductile wrench zones exposed in pre-Alpine granitoid rocks of the Eastern Alps confirms that this may represent a powerful tool enabling geologists to carry out a comprehensive analysis of shear zone evolution. The analyzed structures, characterized by no volume change, display different strain configurations. All structures show heterogeneous deformation increasing from shear zone margins toward the centre, while finite strain profiles across the shear zones suggest that their evolution involved strain softening. Although this characterized both the simple shear and the pure shear components of the deformation, the obtained incremental kinematic vorticity number points out that the pure shear component became progressively less important with increasing deformation. Therefore, simple shear was largely dominant during the late, 'mature' stages of structural evolution, involving strain localization in the softened central sector of the shear zone.

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SESSION S6

Geodynamics and Paleogeography of Tethyan belts: from convergence to exhumation

CONVENERS AND CHAIRPERSONS

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Subduction evolution of the Dinarides and the Cretaceous orogeny in the Eastern Alps: Hints from a new palaeotectonic reconstruction

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Keywords: tectonic palaeoreconstructions, Dinarides, Eastern Alps.

The geological evolution of the Dinarides, Pannonian basin and Eastern Alps has been reconsidered taking into account the constraints obtained from new paleotectonic reconstructions (e.g., Argnani, 2009, 2012). The geological record of the Dinarides shows that one or more oceanic basins existed between Africa and Europe in late Triassic - late Jurassic. Oceanic subduction occurred during late Jurassic - early Cretaceous, leading to westward obduction of oceanic lithosphere above the Drina-Pelagonian microcontinent (Pamic et al., 2002). Following the late Jurassic - early Cretaceous obduction, subduction resumed close to the European margin, and continued until late Eocene, when the Vardar oceanic basin closed, and an ophiolitic melange was emplaced on the Drina–Pelagonian region. Subsequently, during late Eocene-Oligocene, the narrow Pindos-Bosnian ocean was subducted to the east, until its closure caused the Adriatic-Dinaric carbonate platform units to be accreted to the Dinaride fold-and-thrust belt. Plate kinematics indicate that N-S convergence between Africa and Europe initiated only after the Cenomanian, that is well after ophiolite obduction occurred in the Dinarides-Hellenides. Oceanic subduction and continental collision in the Alpine s.s. domain developed from the late Cretaceuos onward (Gebauer, 1999). The only exception is represented by the Eastern Alps, where an early Late Cretaceous orogeny has been recorded (Thoeni, 1999). This tectonic event appears to be separated by the subsequent tectonic evolution, that is linked to the Alps s.s., both in terms of age of deformation, nature of involved terranes, and structural directions, making the Cretaceous orogeny of the Eastern Alps has not been fully understood (Schmid et al., 2008). The new paleoreconstructions suggest that the Pindos-Vardar ocean ended to the NW, against a transform fault that bounded to the south the Austroalpine domain. Within this frame, the problematic Cretaceous orogeny of the Eastern Alps can be explained as linked to the episodes of ophiolite obduction and subsequent shift of tectonic activity that have been recorded in the Dinarides.

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Exotic basement clasts in conglomerates of the Southern Apennines: provenance and implications for the geodynamic evolution of the Central Mediterranean area

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Keywords: Southern Apennines, Central Mediterranean, geodynamics.

The Southern Apennines represent a long, roughly NW-SE chain in the middle of the Central Mediterranean, resulting from the collision between Europe and Africa. Despite the existing huge literature on the area, many important problems still remain unsolved, like the presence of Tertiary conglomerates containing exotic basement clasts.

Their correct interpretation and framing into a wider geodynamic scenario have deep implications on the reconstruction of the evolution of the European and African sedimentary wedges, in particular on the original position of the Meso-Cenozoic sedimentary covers of the Southern Apennines before the opening of the Tyrrhenian Sea.

New evidence favoring a European provenance for these units comes from the reconstruction of the tectonic evolution of the Mesozoic carbonates of Eastern Sardinia (Arragoni *et al*., 2016).

In this work we further support this interpretation by presenting the results of sedimentary, geochemical and petrographic analyses made on the exotic basement-derived clasts of the Tertiary conglomerates. These are found in several scattered outcrops from the Filettino area (NE of Rome, Latium) to the Cilento region (SE of Naples, Campania). The presence of igneous (mainly granitoid and acid porphyric lithologies) and metamorphic clasts is a striking feature whose origin and significance are still debated in the literature. The lack of basement rocks in the Southern Apennines implies that their origin has to be searched in areas where the basement is extensively exposed. These include the Calabro-Peloritani arc and the Sardinia-Corsica block, which in Oligocene time were connected to the Southern Apennines to form a single collisional chain.

The analyses, made on 29 selected samples coming from 4 conglomeratic units (Filettino, Gavignano, Ariano Irpino and Cilento), demonstrate the full compatibility between these exotic clasts and the igneous rocks of Eastern Sardinia. Lithologic, minor elements, and REE compositions of these exotic clasts allow excluding their provenance from the Calabria basement, thus identifying Sardinia as the only possible primary source area.

This has deep implications on the geodynamic reconstruction of the Central Mediterranean area, since it allows linking the Southern Apennines sedimentary covers to the Mesozoic carbonates of Eastern Sardinia. In this way, the western side of the Southern Apennines represents part of the European palaeomargin of the Tethys, deformed during a first tectonic phase in Oligocene time and then detached from its basement (currently located at the bottom of the Tyrrhenian Sea) and transported eastwards into their current position during the opening of the Tyrrhenian Sea since Tortonian time.

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Tectono-sedimentary evolution of the northern Iranian Plateau: insights from middle-late Miocene foreland-basin deposits

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Keywords: orogenic plateau foreland basin intermontane basin shortening and thickneing processes.

Sedimentary basins in the interior of orogenic plateaus can provide unique insights into the early history of plateau evolution and related geodynamic processes. The northern sectors of the Iranian Plateau of the Arabia-Eurasia collision zone offer the unique possibility to study middle-late Miocene terrestrial clastic and volcaniclastic sediments that allow assessing the nascent stages of collisional plateau formation. In particular, these sedimentary archives allow investigating several debated and poorly understood issues associated with the long-term evolution of the Iranian Plateau, including the regional spatio-temporal characteristics of sedimentation and deformation and the mechanisms of plateau growth.

We document that middle-late Miocene crustal shortening and thickening processes led to the growth of a basement-cored range (Takab Range Complex) in the interior of the plateau. This triggered the development of a foreland basin (Great Pari Basin) to the east between 16.5 and 10.7 Ma. By 10.7 Ma, a fast progradation of conglomerates over the foreland strata occurred, most likely during a decrease in flexural subsidence triggered by the onset of rock uplift along an intraforeland basement-cored range (Mahneshan Range Complex). This was in turn followed by the final incorporation of the foreland deposits into the orogenic system and ensuing compartmentalization of the formerly contiguous foreland into several intermontane basins.

Overall, our data suggest that shortening and thickening processes led to the outward and vertical growth of the northern sectors of the Iranian Plateau starting from the middle Miocene. This implies that mantle-flow processes may have had a limited contribution toward building the Iranian Plateau in NW Iran

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Post-Variscan exhumation and thermal history of the Variscan Basement in NE Sardinia: insights from apatite fission-track analysis

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Keywords: Sardinia geology, Thermochronology, Apatite fission track, Exhumation.

A portion of the Variscan basement of NE Sardinia has been investigated by apatite fission-track analysis (AFT), to reconstruct its thermal history and to constrain its recent exhumation. The studied area is located in the Baronie region, NE Sardinia, where a well-exposed section of low to high-grade metamorphic rocks occurs. The deformative and exhumation history of these rocks is relatively well-understood for the Variscan phases and their exhumation is related to a major transpressional tectonic event (Carosi & Palmeri, 2002; Di Vincenzo et al., 2004). On the contrary, very little is known on their more recent history. To fill this gap, samples from the different tectono-metamorphic units, were collected along a N-S transect, perpendicular to the main structural boundaries of the Variscan transpression. Samples yielded AFT ages ranging between 42.7±5.6 and 106±9 Ma, with a general younging trend toward south. Despite the relatively large age range, thermal modelling shows that all samples experienced a rapid exhumation starting at 40–45 Ma. New AFT data and age distribution, coupled with available data from literature (Zattin et al., 2008), suggest a main phase of post-Variscan exhumation in the Eocene. In this context, strike-slip faults with a transpressive component, such as the Monte Albo flower-structure, were already activated since the Eocene (Dieni et al., 2008) and only later on, in Oligocene-Lower Miocene times (Oggiano et al., 2009), were re-activated in a different stress field.

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Tracking sand fairways to develop tectonic restorations in the Western Alps and central Mediterranean

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Keywords: Sand fairway mapping, tectonic restoration, Western Alps, central Mediterranean.

The interplay between regional subsidence mechanisms and local deformation associated with individual fold-thrust structures is commonly investigated in neotectonic subaerial systems using tectonic geomorphology. Taking these approaches back into the early evolution of mountain belts is difficult as much of the key evidence is lost through erosion. The challenge is to develop appropriate tools for investigating these early stages of orogenesis. However, many such systems developed under water. In these settings the connections between regional and local tectonics are manifest in complex bathymetry. Turbidity currents flowing between and across these structures will interact with their substrate and thus their deposits, tied to stratigraphic ages, can chart tectonic evolution. Understanding the depositional processes of the turbidity currents provides substantial further insight on confining seabed geometry and thus can establish significant control on the evolution of bathymetric gradients and continuity through basins. However, reading these records commonly demands working in structurally deformed terrains that hitherto have discouraged sedimentological study. This is now changing. Sand fairway mapping provides a key approach. Fairway maps chart connectivity between basins and hence their relative elevation through time. Larger-scale tectonic reconstructions may be tested by linking fairway maps to sand composition and other provenance data. More detailed turbidite sedimentology provides substantial further insight. In confined turbidite systems, it is the coarser sand component that accumulates in the deeper basin with fines fractionated onto the flanks. Flow bypass, evidenced by abrupt breaks in grading within individual event beds, can be used to predict sand fraction distribution down fairways. Integrating sedimentology into fairway maps can chart syntectonic slope evolution and thus provide high resolution tools equivalent to those in subaerial tectonic geomorphology. The stratigraphic records are preserved in many parts of the Alpine-Mediterranean region. Examples are drawn from the Eo-Oligocene of the western Alps and the early Miocene of the Maghreb-Apennine system to illustrate how turbidite sedimentology, linked to studies of basin structure, can inform understanding of tectonic processes on regional and local scales. In both examples, sediment was delivered across deforming basin arrays containing contractional structures, sourced from beyond the immediate orogenic segments. The depositional systems show that multiple structures were active in parallel, rather than develop in any particular sequence. Both systems show that significant deformation occurs, emerging to the syn-orogenic surface ahead of the main orogenic wedge. The cycling of uplift and subsidence of "massifs" can be significantly more complex that the histories resolved from thermochronological data alone.

An insight on the spatio-temporal evolution of intraplate strike-slip faulting: the Neogene–Quaternary history of the Kuh-e-Faghan Fault system, central Iran

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Keywords: Central Iran, strike-slip faulting, low temperature thermochronology.

Central Iran is an ideal test site to study the long-term morphotectonic response to enucleation and propagation of intraplate faulting. In this study, a multidisciplinary approach that integrates structural and stratigraphic field investigations with and thermochronological (apatite fission track (AFT), (U-Th)/He on apatite (AHe), and on ematite (HeHe)) analyses, is used to reconstruct the spatio-temporal evolution of the Kuh-e-Faghan Fault (KFF), in northeaster Central Iran. Structural mapping reveals that KFF defines a narrow, ca. 80 km long, deformation zone consisting of three main broadly left stepping, E-W trending, right-lateral fault strands which cut through the Mesozoic-Paleozoic substratum and the Neogene-Quaternary sedimentary covers. The AHe thermochronology results indicate that the intra-fault blocks along the KFF experienced two major episodes of fault-related exhumation at ~18 Ma and ~4 Ma. The first faulting/exhumation episode at ~18 Ma is chiefly recorded by the Neogene deposits architecture along the KFF. In particular, a source-to-sink scenario can be reconstructed for this time frame, when topographic growth caused the synchronous erosion/exhumation of the pre-Neogene units and deposition of the eroded material in the surrounding fault-bounded continental depocenters. Successively, the KFF gradually entered a period of relative tectonic quiescence and, probably, regional subsidence during which a thick pile of fine-grained onlapping sediments were deposited, causing the resetting of the (U-Th)/He system of the detritic apatite grains hosted both within the pre-Neogene and the basal Neogene successions. AFT dating indicates that the basement units, that are now exposed to the surface, where most probably below the closure temperature (100-120 °C) of the AFT system during the first exhumation event and, similarly, the AFT system of the pre-Neogene and Neogene deposits have not been reset by Miocene burial (>4 Ma). Together, the AHe and AFT data from the Neogene basin sediments imply burial temperatures in excess of ~60 °C and less than 100 °C. The second faulting episode at ~4 Ma caused the final fault exhumation event, resulting in the current fault zone and topographic architecture. The HeHe ages of hematite coated fault surfaces register both formation ages during the first exhumation event (>6-4Ma) and exhumation ages during the second exhumation event (<6-4 Ma), thus confirming the polyphase history of the KFF system. Collectively the stratigraphic, structural and thermochronological datasets shows that the KFF enucleated in the west and propagated eastward in two punctuated events. The major outcomes of this study have important implications on (i) understanding the propagation and spatio-temporal evolution of intraplate strike-slip fault systems; (ii) the intraplate response to tectonic reorganization at the collisional boundaries; and (iii) the Neogene-Quaternary kinematic and tectonic evolution of Central Iran.

Vorticty of the flow and strain analysis in the Argentera Massif (External Crystalline Massifs, Western Alps): recognition of a regional pure-shear dominated transpression

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Keywords: Variscan shear zone, Argentera Massif, mylonites, transpression, East Variscan shear zone.

Microstructural analysis, kinematic vorticity and finite strain analysis were performed on mylonites from the Ferriere-Mollières shear zone (FMSZ), a Variscan regional-scale shear zone cross-cutting the Argentera Massif (Western Alps). Mylonites show medium to high-grade paragenesis but in the most sheared portion paragenesis of a lower metamorphic grade have been indentified suggesting retro-metamorphism. A deformation gradient has been observed towards the core of the shear zone. Kinematic vorticity analysis was performed using the stable porphyroclasts method (Passchier, 1987; Wallis et al., 1993) and the S-C' planes method (Kurz & Northrup, 2008). The finite strain analysis was performed using center-to-center method (Fry, 1979). The data collected along three transects indicate that the FMSZ is characterized by a dextral transpressive deformation with a prevalent pure shear associated with simple shear. It was recognized an increase of simple shear from the marginal portions of the shear zones towards the center. The deformation is characterized by oblate strain ellipsoids in the marginal parts of the shear zone and prolate strain ellipsoids in its central part. Combining vorticity and finite strain (Law et al., 2004) a 24,5% of shortening was estimated. This data-set allow us to infer that the Ferriere-Mollières shear zone has been subject to a type II evolution (Fossen, 2010). The geological and structural setting of FMSZ is similar to that outlined for the Sardinian Variscan basement (Carosi et al., 2012) and the Maures-Tanneron Massif (Corsini & Rolland, 2009) and allow to insert the FMSZ in the East Varisican Shear Zone context.

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Exhumation of the metamorphic core of the Himalayas: myths and reality

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Keywords: Himalayan belt, collision, exhumation, Greater Himalyan Sequence, tectonic discontinuity.

The understanding of exhumation mechanisms of deep-seated metamorphic rocks in collisional orogens has been improved by the discovery of contemporaneous contractional and normal-sense shear zones active in the same vertical section in orogenic belts such as the Hellenides, Canadian Cordillera, Appalachians, Western Alps and the Variscan belt. The normal sense top-to-the-NE South Tibetan Detachment (STD) and the contractional top-to-the-SW Main Central Thrust (MCT), bound the crystalline core of the belt, the Greater Himalayan Sequence (GHS), in the Himalayas, to the top and to the bottom respectively. They are regarded as the most classic example of a coupled faults/shear zones acting contemporaneously but with opposite kinematics in a collisional belt. They were active between ~ 24 and 17 Ma. The STD and MCT play a fundamental role in all the tectonic models envisaged for the exhumation of the GHS such as: extrusion, channel flow, channel flow followed by extrusion, critical taper and wedge insertion. In this framework the GHS has been always regarded as a coherent tectonic units exhumed mainly by the shearing along the STD and MCT.

Field-based work followed by structural and petrographic analysis joined with in situ geochronology in the central part of the Himalayas allowed to recognize an internal tectonic organization of the GHS far from a simple ductile wedge or channel of melted rocks.

A regional-scale tectonic discontinuity (Higher Himalayan Discontinuity: Montomoli et al., 2013, 2015), stretching for nearly 800 km along the belt, has been recognized within the GHS active between 27 and 17 Ma. Its activity triggered the exhumation of its hanging-wall before the activation of the MCT whereas the footwall continued to underwent increasing P and T. A higher and older tectonic discontinuity has been recognized in the uppermost part of the GHS active since the Middle Eocene and triggering the earliest exhumation of the GHS at ~ 41-30 Ma. In Western Nepal the activity of the STD has been constrained to be > 24 Ma whereas the MCT is much younger, between ~ 17 and 13 Ma.

The new data do not confirm the previous models of exhumation of the GHS mainly driven by the MCT and STD but need a new model to explain the occurrence of the regional discontinuities within the GHS active since ~ 41 Ma and the lacking of the contemporaneous activity of the STD and MCT.

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The Main Central Thrust Zone activity in Garhwal (India, NW Himalaya): insights from geochronological and microthermometric studies

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Keywords: Himalayan belt, Main Central Thrust Zone, geochronology, microthermometry.

The Greater Himalayan Sequence (GHS) plays a key role in understanding the evolution of the Himalayan orogen. The GHS is delimited by two systems of shear zones: the South Tibetan Detachment System (STDS) at the top and the Main Central Thrust Zone (MCTZ) at the bottom. To constrain the time of activity of the Vaikrita Thrust (VT; the upper part of the MCTZ), in situ geochronological datings on monazite were performed on a garnet-staurolite bearing micaschist and a garnet-kyanite bearing paragneiss.

Isotopic and chemical data show a relationship between chemistry and the age of monazites microdomains. Medium-low Y monazite cores and mantles, constrain the age of prograde metamorphism at c. 30-23 Ma, whereas the retrogression phase is pointed out by high-Y monazite rims, at c. 20-15 Ma.

$^{40}Ar/^{39}Ar$ stepheating ages were obtained on biotite and muscovite, separated from a garnet staurolite quartzite and from two garnet-bearing micaschists of the VT. Biotite and muscovite give an age of 9-10 Ma and 6-7 Ma respectively. The same ages were also reported by Sen et al. (2015), who however proposed a different interpretation from ours below.

Metamorphic constraints on the former samples have been obtained with the P-T-X pseudosection modeling coupled with inverse geothermobarometry, pointing to an increase of P-T conditions from c. 560 °C - 0.85 GPa up to c. 690 °C - 1.20 GPa, in agreement with Thakur et al. (2015).

A microthermometric study was carried out on fluid inclusions in quartz from syntectonic veins of the Munsiari Thrust (MT), the lower part of the MCTZ. With a trapping temperature range of 500-580 °C, suggested by quartz microstructures and data from Célérier et al. (2009), a trapping pressure range of 0.50-0.61 GPa is estimated.

Our data represent the first geochronological constraints obtained on monazite for the study area. The end of the prograde and the beginning of the retrograde path recorded by monazite highlights the earlier shearing of the MCT. Muscovite ages constrain the timing of static mineral growth across the S2 foliation around 6-7 Ma during the final phases of exhumation. In summary, we documented a long-lived shearing activity in the VT and MT between c. 20 Ma and c. 6 Ma.

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Geological map of the Liguride Complex of the Pollino area (Southern Apennines)

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Keywords: Geological Map, Liguride Complex, Southern Apennines.

The calabro-lucanian sector of the southern Apennines shows evidence of the major paleogeographic domains derived from the Alpine Tethys and the Adria plate. Therefore, it is a key area for understanding the geodynamic evolution of western-central Mediterranean. Our study shows the results of detailed geological-structural mapping as well as minero-petrographic and petrological studies aimed at reconstructing the tectono-stratigraphic relationships among different units of the Liguride Complex.

In the investigated area the Liguride Complex is about 1 km thick and tectonically overlies the upper Burdigalian clastic unit on top of the Apennine carbonate Platform. In turn, it is covered by thrust top siliciclastic and carbonatoclastic deposits of the Albidona and Perosa Fms and, finally, by Pleistocene clastic deposits of the Sant'Arcangelo basin.

Geological-structural mapping allowed to distinguish three major tectonic units, characterized by an overall decrease of metamorphic grade from top to bottom, namely: i) the Frido Unit; ii) the Seluci-Cogliandrino Unit and iii) the Nord Calabrian Unit. The base of the Frido Unit consists of serpentinites, foliated metabasites and M. Nandiniello Metalimestones, frequently occurring in an overturned succession. In the western sector, metabreccias and metarenites are present between metabasites and the M. Nandiniello Metalimestones. In the northern sector, a typical seafloor sequence consisting of weathered metabasites, red jaspers, gray metalimestones and siliceous slates can be recognized. Upward, the Frido Unit consists of gray slates with intercalations of fine-grained, grey-green metalimestones and quarzites. More to the East, the M. Caramola Metalimestones (Oligocene) may represent the top of the succession. In the San Severino Lucano - Episcopia area, slices of serpentinites are widespread at the top of the metasediments. In the northern sector, they are covered by slices of continental crust rocks consisting of Albitic gneisses, Garnet gneisses and Amphibolites. Phyllosilicates of metasediments from the Frido Unit suggest HP/LT metamorphism with a wide range in P-T values (P: 6-13 kbar; T: 200-330 °C). These estimates are in agreement with the presence of carpholite and aragonite in the metasediments as well as with the occurrence of glaucophane and lawsonite in the metabasites.

The Seluci-Cogliandrino Unit consists mostly of metapelites characterized by a main foliation and incipient crenulations. Preliminary data on phyllosilicates from this unit suggest P-T conditions of 7 kbar and 160-200 °C.

The Nord Calabrian Unit mainly outcrops in the eastern sector and it is represented, from the bottom, by the Timpa delle Murge Ophiolites, the radiolarites and shales of the Timpa delle Murge Fm., the Crete Nere and the Saraceno Fms, covered by the Miocene thrust top deposits of the Albidona Fm. Phyllosilicates of the Crete Nere and Saraceno Fms constrain P-T conditions at the lower part of high diagenesis.

The tectonic evolution of the Yalaxiangbo gneiss dome, SE Tibet

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Keywords: Yalaxiangbo, gneiss domes, tectonic evolution.

The Northern Himalayan Gneiss Domes belt (NHGD) consists of a series of E-W-striking gneiss domes, exposed in the core of Tethyan Sedimentary Sequence (TSS), stretching parallel to the Himalayan belt. The Yalaxiangbo gneiss dome is one of the most important domes in NHGD in eastern Himalaya. It is divided into three main tectonic units by a brittle upper and a ductile lower detachment shear zone. The upper unit is formed by unmetamorphosed to low-grade metamorphic Triassic-Lower Cretaceous slate and metasandstone lying above the brittle upper detachment. The middle unit, subdivided into two sub-units by a minor detachment fault, is composed by phyllite and micashist. The phyllite consists of white mica, quartz, garnet, staurolite and ilmenite. Mineral lineation in phyllite is made by white mica, garnet and ilmenite. The micashist consists of biotite, muscovite and quartz minor plagioclase and garnets. The penetrative mineral lineation is composed of micas and stretched quartz. The lower unit consists of mylonitic gneiss, a leucogranite pluton and associated dikes and sills, lying below the lower ductile detachment shear zone.

The fabric of the D_1 deformation phase is well-developed in the TSS. It is related to a top-to-the south contractional deformation, reflecting a regional N-S shortening. Sedimentary bedding (S_0) has been overprinted by a penetrative S1 foliation related to a southward thrusting. The D_2 deformation phase is related to a top-to-the N extensional tectonics, characterized by a mainly brittle deformation in the upper detachment and a ductile deformation below. The D_2 metamorphic mineral assemblage within the upper brittle fault consists of Ms/Ser+Chl+Pl+Qz, suggesting a deformation under greenschist-facies conditions. The D_2 metamorphic mineral assemblage within the lower ductile shear zone consists of Ms+Pl+Bi+Grt+Qz¡ÀHbl¡ÀSt, which indicates upper greenschist to lower amphibolite facies metamorphism. The D_3 deformation phase with a centrifuge sense of shear with respect to the culmination of the gneiss dome can be related to the late diapiric ascent of the leucogranite pluton inside the dome (Yan et al., 2012).

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A review of the deep structure of central Mediterranean and inference for the geodynamic evolution

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Keywords: Lithosphere Structure, geodynamic evolution, central Mediterranean.

Decades of seismological studies contribute to the imaging of the earth structure in the central Mediterranean area, with resolution scale spanning from kilometers to hundred of kilometers. Complementary to active seismic profiles, the use passive seismic data became a cheaper alternative for the definition of the lithosphere/asthenosphere structure. The strong improvement of observational networks, the wide collection of data achieved in the past decades, and the new massive-data crunching techniques permit to create progressively refined 3D models of the earth structure.

After first attempts in the early 90's, seismological studies progressively re-focused blobs of high velocity anomalies in the mantle beneath the Alpine and Apennine systems. Such bodies have been thought as evidence of lithospheric material, belonging to the Tethys and Neo-Tethys oceans, subducted almost continuously since the late Mesozoic. After the early reconstructions of the central Mediterranean evolution, more refined models of slab retreat, slab detachment, slab tearing, lithospheric delamination and dynamic topography have been proposed for the area. All these models are derived by gross-scale P-wave velocity anomalies in the mantle. Anyway the interpretation of P-wave velocity anomalies only in terms of different temperature - and density - in the mantle may be questionable and could result in a strong overestimation of the subducted lithosphere. This consideration urged the use and integration of techniques and models, able to include in the suite of physical parameters Vs and Vp/Vs models that better discriminate if mantle anomalies are related to thermal or compositional effects.

In this work, we review some former models, acknowledge some recent results and propose ideas for future investigation. High resolution Vs and Vp/Vs tomographic images of the lithosphere and upper mantle are jointly used with Receiver Function velocity models to give a consistent view of the deep earth. Although the first order reconstruction is mostly similar to that achieved by Vp models, some new insight on the physical state of the upper mantle and refinements in the extent of subducted material can be possible.

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The Ligurian domain in the southern Apennines and northern Calabria

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Keywords:Ligurian Ocean, ophiolites, southern Apennines, Calabria.

The Ligurian units cropping out in the southern Apennines and northern Calabria include the sedimentary successions of Nord-Calabrese and Parasicilide/Sicilide and the metamorphic successions of Frido and Calabrian ophiolites. The Nord-Calabrese and Parasicilide/Sicilide units (Ciarcia et al., 2009; 2012; Vitale et al., 2011; 2013a) are formed by Upper Cretaceous-lower Miocene deep basin successions characterized by dominant argillites at base and siliciclastic and calciclastic turbidites on the top, finally passing to foredeep sandstones. The Nord-Calabrese unit shows at base olistoliths of ophiolites whereas the Parasicilide blocks of dolerites. The Frido Unit (Vitale et al., 2013b) is formed by an Ocean-Continental-Transition (OCT) basement made of Jurassic serpentinites and metabaslats and Paleozoic continental rocks covered by Mesozoic-upper Oligocene metaradiolarites, phyllites, calcite mylonites and metarenites. The unit is affected by an HP/VLT metamorphism. These successions extensively exposed in the southern Apennines are located in the highest structural level of the orogenic belt. In the northern Calabria corresponding ophiolite sequences are sandwiched between the Calabride units on the top and the Apennine units on the bottom. The successions, grouped in main three units (Diamante-Terranova, Gimigliano and Malvito) include Jurassic metabasalts at base and Mesozoic metaradiolarites, phyllites, calcite mylonites and meta-cherty limestones. These successions are characterized by a HP/LT metamorphism. A complete correspondence exists between the southern Ligurian units and those cropping out in the northern Apennines as well as similarities with the Maghrebian Flysch Basin units exposed in Sicily, northern Africa and Betic cordillera.

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The Belluno Thrust between Monte Coppolo and Monte Agraro (Eastern Southern Alps, Northern Italy)

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Keywords: Thrust architecture, folds, shear zones.

The Eastern Southern Alps are a southverging postcollisional thin skinned chain, which develop between Periadriatic Lineament and Venetian Plain in Northern Italy. Four are the main thrusts building the chain: Marmolada, Valsugana, Belluno and Bassano Thrusts. Marmolada is a pellicular structure involving Upper Permian-Middle Triassic succession; Belluno represents the propagation of Valsugana indentation involving the crystalline basement intruded by Lower Permian Cima d'Asta body; Bassano and Montello are the more recent foothills structures. All these thrusts are N90 to N70 oriented, propagating southwards from Early Miocene to Recent (Castellarin et al., 2006). At M. Coppolo the stratigraphic sequence includes the peritidal dolostones of Upper Triassic Dolomia Principale and the peritidal limestones of Calcari Grigi Group. It includes M. Zugna Fm. with abundant chert nodules, defining a strong subtidal environment, Loppio Oolite, Rotzo Fm. and Toarcian Grigno Oolite (Trevisani, 1991), very similar to Massone Oolite of Sarca Valley. These oolitic bars mark the western and eastern border of Trento Platform during Lias. Aalenian encrinites of San Vigilio Oolite, Middle-Upper Jurassic Rosso Ammonitico, Lower Cretaceous Maiolica and Upper Cretaceous Scaglia Rossa Fms follow, marking the final drowing of Trento Platform causing pelagic conditions. The Belluno Thrust (BT), W-E oriented, extends from Pieve Tesino to Caporetto bordering the northern margin of Belluno syncline (D'Alberto et al., 1995). BT is highlighted by anticline of M. Coppolo–M. Agaro, involving the entire stratigraphic succession with the northern limb gently dipping northwards (Brocon Pass) and the southern one vertical to overturned. The Belluno Thrust split into three southverging structures from North to South: M. Piad Line, a steep deepening reverse fault cutting the M. Coppolo Anticline hinge; Sasso Falares Line dipping 50° northwards along which the Coppolo Anticline thrusts over the Calcari Grigi-Maiolica succession arranged in an another anticline representing the Sasso Falares-Val Nuvola Duplex (SFVND); Belluno Line s.s. dipping 30° northwards, along which M. Zugna Fm. thrusts over Maiolica, bordering southwards the SFVND. The shortening is about 5-6 km. A new outcrop of BT at Pugnai shows the architecture of thrust.

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Syn-shearing temperatures constrained via thermodynamic modelling during the ductile strain-rate evolution in the Symvolon syn-extensional plutonic body (Rhodope core complex, Greece)

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Keywords:X-Ray maps, Multivariate statistical analysis, Effective bulk rock chemistry.

Syn-extensional crustal-scale shear zones are one of the preferential uplifting route for the emplacement of plutonic bodies. Field evidences of these emplacement mechanisms have to be recognized in the occurrence of gradually increasing mylonitic fabric from the centre to the periphery of the plutonic body, also overprinting the host rock fabric at its direct boundary.

The mylonitic granodiorites of the syn-tectonic Symvolon pluton (Punturo et al., 2014), at the south-western boundary of the Rhodope Core Complex (Greece), results to be significant to constrain the strain-rate evolution of a syn-shearing plutonic body emplacement, useful to better constrain the complex early Miocene geodynamic scenario of this sector of Eastern Mediterranean realm.

Strain-rate values were here obtained, after the definition of the syn-shearing temperature estimations, constrained via image processing of X-Ray maps of selected porphyroclastic domains, useful to obtain the effective bulk rock chemistry operating during the mylonitic development. Yielded temperatures, probably linked also with the cooling gradient from the centre to the periphery of the pluton, were then used to constrain the strain-rate using a combination of a paleopiezometer (Shimizu, 2008) and a quartz flow law (Hirth et al., 2001).

Obtained results, associated with a detailed cooling history (Dinter et al., 1995), allowed us to reconstruct the joined cooling and strain gradient evolution of the pluton from its emplacement during early Miocene (~700°C at 22 Ma) to its following cooling stage (~500-300°C at 15 Ma).

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Detailed characterizaton of mixed-layer illite/smectite, a useful tool for geodynamic recostruction. A case study of southern Apennines

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Keywords: Mixed-layer illite/smectite, geodynamic, southern Apennines.

Reconstruction of thrust sheet thermal history is crucial to define emplacement and pattern of tectonic loading and to determine final geodynamic evolution of an area.

In this paper, clay mineralogy was used as a tool to study differences in thermal maturity and to determine emplacement of thrust sheets in a wide sector of southern Apennines characterized by the presence of clayly sequence submitted to tectonic loads of a few kilometres. In detail, mixed layers illite-smectite (I-S) features of 56 samples collected from Lower Cretaceus Galestri Formation were studied by X-ray powder diffraction.

Galestri Formation is characterized by a monotonous facies formed by alternance of carbonates and shales sometimes silicified. This monotonous stratigraphic alternance outcropping at regional scale and permits to avoid the compositional variations acting on the illitization process of smectite. Moreover, since it represent a single formation the time effect on the diagenesis is minimised.

Galestri Formation is deposited within the Lagonegro basin derived from a wide basin located between the Apenninic Platform and the Apulia Platform. The Lagonegro Units are constituted of two major thrust sheets. The upper thrust sheet (Lagonegro Unit II) is characterized by middle Triassic to lower Cretaceous basinal marine deposits with abundant shallow-waterderived carbonate material. The lower thrust sheet (Lagonegro Unit I) is composed of upper Triassic-lower Cretaceous deep-water deposits displaying more distal characteristics than the coeval deposits of the Lagonegro Unit II. These successions form the ancient core of southern Appennines exposed along the axial zone of the chain. The data show a strong variation between the two Lagonegro units in terms of thermal maturity. In fact, the samples collated from Lagonegro Unit II are characterized by the presence of R0 illite (25-55%)/S and R1 illite (60-70%)/S whereas the samples from deeper unit (Lagonegro Unit I) display R1 illite (65-85%)/S. Moreover, thermal maturity shows a increasing trend from North to South along the axial zone of the chain thus suggesting an increase in structural stacking. This structural setting is in accordance with the regional cross-sections presented by some authors explaining general southward increasing amounts of shortening as well as with southward increasing backarc extension in the Tyrrhenian Sea. These contractional and extensional processes are roughly balanced each other being both driven by passive sinking of the Adriatic-Ionian lithosphere.

3D velocity model from tomographic analysis of seismic reflection data in the Gulf of Trieste (North Adriatic sea)

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Keywords: Gulf of Trieste, Dinaric and Southern Alpine foreland, multichannel seismic reflection data.

The Gulf of Trieste (NE Adriatic) is settled in the corner between the External Dinaric and the Southern Alpine chains, trending respectively NW-SE and E-W. The gulf is the foredeep of both the orogens and its geological setting is the result of a multiphase tectonic activity: 1) the Mesozoic rifting, that generated NW-SE normal faults allowing the aggradation of the Mesozoic-Paleogenic Friuli-Dinaric Carbonate Platform; 2) the Dinaric compression (Upper Cretaceous-Paleogene), that induced the E-ward dipping of the platform and led to the deposition of Eocene turbidites (Flysch); 3) the Alpine compression (Oligocene-Late Cenozoic), that tilted the platform N-ward and reactivated the Mesozoic-early Cenozoic structures with a dextral transcurrent/transpressive motion (Busetti et al., 2010). Seismic interpretation on marine multichannel seismic reflection profiles, acquired in 2005, 2009 and 2013, showed that the platform is vertically displaced of more of 1500 m by the Karst Thrust (the Dinaric frontal ramp along the eastern coast of the gulf). Offshore, the top of the Flysch is depicted by Messinian erosion and draped by Plio-Quaternary marine and continental deposits. This surface is affected by fault systems indicating neotectonic activity and providing paths for fluids migration from the carbonates (Busetti et al., 2013).

The available geophysical datasets in the Gulf of Trieste are used in this study to perform a tomographic analysis to obtain a 3D velocity model of the subsurface. This is crucial for the definition of a 3D geological depth model that would also help a deeper understanding of the neotectonic behavior of the area. After the picking of the traveltimes on raw data, the tomographic inversion was executed by using the Simultaneous Iterative Reconstruction Technique (SIRT) and a code based on the principle of the minimum dispersion of the estimated reflection/refraction points (Carrion et al., 1993). These methods estimate respectively the velocity field and the surface's depth and shape, through an iterative process. When a chosen value of difference between the last model and the previous one was reached, the process was stopped and the result's reliability was evaluated by computing the traveltime residuals.

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U/Pb zircon dating and pre-Alpine evolution of the Grand St Bernard nappe system in the Aosta valley, Italian Western Alps

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Keywords: U/Pb zircon dating, geochemistry, Grand St Bernard nappe, Ordovician magmatism, Variscan orogeny.

The Grand St Bernard-Briançonnais nappe system crops out along the arc of the Western Alps, as a first-rank component of the Austroalpine-Penninic collisional wedge. In spite of its blueschist- to greenschist-facies tectono-metamorphic reworking during the Alpine orogeny, significant relics of Permian, Variscan and older igneous and high-grade metamorphic events are preserved within some units of the nappe stack, supporting the existence of two paired belts characterized by contrasting Variscan features. New SHRIMP U/Pb zircon and geochemical whole rock analyses of gneissic bodies derived from acidic intrusive and subvolcanic bodies suggest:

i) The occurrence of two geochemically different Ordovician magmatic events. Samples from Ruitor massif (459.0 ± 2.3 and 456.4 ± 2.4 Ma) are high-K calcalkaline granitic protoliths with geochemical features consistent with those of modern continental granitoids. Guillot et al (2002) reported Ordovician emplacement ages (IDTIMS and SIMS U-Pb analyses on zircon; upper intercepts of 460 ± 7, 468 ± 22 and 471 ± 5 Ma) for other granitic samples occurring in the Ruitor basement. Metagranophyres from the Leverogne Unit (465.0 ± 2.5 Ma) instead show alkali A-type chemical signature plotting in within-plate granite field. Bertrand et al. (2000) interpreted a poorly constrained upper intercept of 511 ± 9 Ma (IDTIMS U-Pb on zircon) as the magmatic age of two samples of the same metagranophyre body;

ii) The innovative Devonian-Carboniferous emplacement age of the Gran Nomenon Unit is confirmed (371 ± 0.9 Ma). These samples are magnesian calc-alkalic granitoids having typical arc-related geochemical signature. Similar emplacement age and geochemical behavior are found in magmatic samples of the Monte Canale Unit (Lower Austroalpine) in the Central Alps;

iii) Permian emplacement age of 279.1 ± 1.1 Ma for magmatic protolith from the Costa Citrin Unit (Houillère zone). This sample plots close to the boundary between high-K calcalkaline and shoshonitic series and can be classified as transitional A-type ferroan alkali-calcic granite. Bertrand et al. (1998) reported two poorly constrained upper intercepts at 324 ± 24 and 323 ± 7 Ma (IDTIMS U-Pb on zircon) for two metagranites occurring in the same unit;

iv) The absence in the GSB Internal belt (Leverogne and Gran Nomenon) of a pre-Alpine, Ruitor-type high-grade metamorphism is corroborated, as well as its along-strike correlation to the Mont Fort nappe (Gouffon, 1993).

The Variscan tectono-metamorphic history of the Internal belt is very different from that recorded by the External belt and other polycyclic Penninic and Helvetic basement units of the Western Alps suggesting an independent geodynamic evolution before their amalgamation which probably occurred during the Late Carboniferous continental collision due to evidence of Permian magmatism throughout the basement units of the Austroalpine-Penninic wedge and the Southern Alps.

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Piedmont-Ligurian rifted margins geometry: preservation of a rift-polarity flip inside the Alpine belt

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Keywords: Rifted margins, Southalpine domain, Palaeogeography, Tectonics.

The rifted margin system of the Alps preserves evidence for Mesozoic multistage magma-poor rifting that finally led to the opening of the "Piedmont Ligurian Ocean". This latter developed through a process of exhumation of the sub-continental mantle along extensional detachment faults. Recently, coupled observations of present-day margins and fossil analogues exposed in mountain belts have been used to unravel the processes of hyperextension and to predict the related sedimentary architecture. The first-order characters on this topic have been suggested by Sutra *et al.* (2013) and Tugend *et al.* (2014). These authors developed a general framework to approach the geometry on different margins integrating the knowledge on the proximal and distal part of a rift system. Moreover they detailed and upgraded the pristine concepts of Upper and Lower plate originally introduced by Lister *et al.* (1986), to explain magma-poor rifted margins evolution. In this study we apply these concepts to two type-sections across the Alpine margins currently located on either sides of the Periadriatic line: the Ligurian Briançonnais and the Southalpine margin. The analysis of their well known stratigraphic records allow the recognition of the main key-areas, *i.e.* the proximal and distal domain separated by necking zones and the exhumed domain. From this first-order analysis we recognized a similar architecture for the two sections that is consistent with a typical Upper plate type margin. This view differs from the previous interpretations, where the studied margins were considered as coupled (*i.e*. Briançonnais as upper plate and Southalpine as lower plate) and possibly even directly conjugates. Following our interpretation the Briançonnais and the Southalpine are coevally-developed margins, respectively resting North and South of a major transform zone (at present roughly represented by the Periadriatic line) that accommodate a flip in the polarity of the rift system during Middle Jurassic. This interpretation leads to important implications for the overall structure of the Jurassic Alpine rifting but also for the significance of the main tectonic structures of the Alps and for their palaeogeographic evolution, opening new question about the role of rifting-related inheritance of the late compressional structures inside orogens.

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The blueschists-facies metapelites of Corte slices (Corsica, France): microtectonic and geothermobarometric constraints for the Alpine metamorphism

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Keywords: Alpine Corsica, Corte Slices, blueschists facies, metapelites, microtectonics.

The so-called Corte Slices includes a group of continental units outcropping in the central area of the Corte island. They represent the remnants of the european paleomargin involved in the subduction and accretion to the alpine orogenic wedge; their present-day structural stacking above the unmetamorphosed Variscan bsement suggests that these slices were deformed at depth at P/T conditions related to blueschists facies metamorphism and then exhumed by polyphase deformation under retrograde P/T conditions. The Corte Slices are made of a paleozoic basement intruded by metagranites, covered by a carbonatic mesozoic succession; the youngest litotypes are Tertiary metabreccias and metaturbidites, lying in angular unconformity above the basement and mesozoic cover. The investigated samples from Popolasca-Castiglione Unit and Piedigriggio-Prato Unit belong to the Metabreccias Fm., that is a siliciclastic deposits of the Middle Eocene characterized by pelitic matrix composed of chlorite, white mica, quartz, albite and calcite. This matrix shows complex microtectonic fabric including well-developed foliations, defined by the preferred orientation of phyllosilicates, thin quartz and feldspa ribbons. Two generation of chlorite-white mica couples have been recognized on the base of their chemistry but also by their microstructural setting. The systematic variation in chemical compositions of these minerals points to a variation from high pressure and low temperature to low pressure and high temperature for the S1 assemblage. Applying geobarometers, thermometers and the multiequilibrium approach (Vidal et al., 2006) based on Si, Al, Fe and Mg contents, the values of pressure and temperature obtained vary from 10.4 kbar and 200°C to 5.1 kbar and 400°C. The younger generation of chlorite and white mica couples complies with P-T conditions of low-grade greenschists, and the values range from 3.1 kbar and 300° to 2.3 kbar and 240°C. From our first investigations it is concluded that the exhumation of the Corte Slices started during the D1 phase, as confirms the decrease of the pressure values obtained by mineral association that constitutes the S1 foliation.

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Pliocene-Quaternary non-coaxial kinematic evolution of the area between M. Raparo and M. Alpi (Lucania Apennines)

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Keywords: Non-coaxial kinematic evolution, transpressive and reverse faults, Plio-Quaternary.

The area stretching between M. Alpi and M. Raparo is a key sector for understanding the structural geometry of the Lucanian segment of the Southern Apennines because the main tectonic units (Ligurid, Apenninic platform, Lagonegro and Apulia platform units) involved in the orogenic edifice are exposed therein. In particular the Apulian platform, which everywhere else in the Apennines is buried underneath a thick allochthonous pile, outcrops there at the Mt. Alpi ridge.

A detailed structural analysis of the main brittle faults has allowed to recognize an alternation of five non-coaxial deformation phases that often led to polyphase faults displacements under different kinematic regimes. An early extensional phase with NE-SW and NW-SE tensile axes is documented in the M. Alpi unit, and is related to syntectonic deposition (Ortolani and Torre, 1971); this extension is also documented here for the first time by rotated normal faults in the Armizzone (Lagonegro) unit. Extension in both units is attributed to Miocene forebulge stretching before their incorporation within the thrust belt. The second phase (Miocene through early Pliocene) is represented by the long-lasting thrust imbrication between Ligurid, Apenninic and Lagonegro units and their overthrusting above the M. Alpi unit. Thin-skinned thrusting occurred under a broad ~E-W shortening, but a clear kinematic reconstruction is hampered by the severe disruption and distortion of these contacts during later deformation stages. The third deformation is recorded in all the tectonic units and is accommodated by reverse and transpressional faults active with a ~NNE-SSW (locally NNW-SSE) shortening axis. These deep-seated faults are related to the late Pliocene involvement of M. Alpi and other buried Apulian units in the main orogenic building (Van Dijk et al., 2000), and formed upper-crustal pop-ups involving the overlying Apenninic and Lagonegro units. A later (late Pliocene-early Pleistocene) phase with an ~E-W shortening axis led to tectonic uplift of the western side of M. Alpi along a sub-vertical N-S striking back-thrust fault. Possibly, a co-axial low-angle extensional fault (Mazzoli et al., 2014) accompanied structural unroofing of M. Alpi in the eastern part of the area. The fact that M. Alpi had already been uplifted along the E-W striking structure underlying its northern front explains the remarkable structural throws across the area, which are difficult to explain in a context of coaxial deformation involving only uplift along its western front. A final (late Quaternary?) extension occurred on limited-length fault segments and is likely related to local isostatic collapse of the over-steepened thrust pile. Results of this work, beside bearing a contribution to unraveling the kinematic evolution of the area, provide a conceptual frame for better understanding the structural evolution of the buried Apulian platform in other sectors of the Apennines.

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New multi-approach constrains for the poliphase evolution of eclogite-blueschist boundary between ophiolitic units in the Susa Valley (Western Alps)

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Keywords: Western Alps, Exhumation, Ophiolites, Kinematism.

New structural and petrological data are collected in the Mid-Susa Valley, along the boundary between eclogite and blueschist ophiolitic units. This boundary is marked by a huge (300-600 m thick) shear zone, named Susa Shear Zone (SSZ, Gasco et al., 2011), that allow eclogitic units (Zermatt-Saas-like Units and Dora Maira Unit) to be exhumed under blueschist units (Combin-like Units).

The SSZ is regionally located in the western limb of the dome structure involving Dora Maira Unit and the overlying Zermatt-Saas Units. The shear zone shows a block-in-matrix structure and well recalls a tectonic mélange (*sensu* Festa et al., 2010). The blocks consist of different litotypes (mafic and ultramafic rocks, marble, paragneiss) embedded in a less competent matrix made up of mylonitic calcschist.

Two mylonitic event sare observed both on the field and in oriented thin sections. The first event occurred during early exhumation stage and is marked by remnants of a tectonic contact with Top-to-E kinematism. The latter are particularly well-defined by S-C structures, and porphyroblasts rotated within a mylonitic foliation. The second event is related to late exhumation and is marked by a shear zones with Top-to-W kinematism.

The two mylonitic events occur under different metamorphic conditions. The analyses of the Si content in the white mica, shows a gap of almost 10-13 kbar between the two mylonytic events, with P of almost 15-18 kbar for the first event(Top-to-E), and 5 kbar for the second event(Top-to-W).

Different textural features in deformation, kinematism and P-T conditions allow to infer the geodynamic evolution as a two main stages: (i) a pre-doming extensional Top-to-E shear zone, corresponding to the early stage exhumation of the eclogitic units along the subduction channel, and (ii) a Top-to-W extensional shear zone, due to the growth of the regional dome structure, corresponding to the late stage of exhumation. The original geometry of the structures referred to first mylonitic event are now significantly modified due to doming of eclogitic units. In fact kinematic indicators show apparently reverse sense of shear.

In conclusion, it is to be emphasized the extensional Top-to-E kinematism of early movement along the SSZ. This early shear zone was subsequently overturned by a deformation phase, testified by large-scale folds giving the dome structure to the axial belt. Finally, a further extensional phase developed by extensional movement Top-to-W and related to the onset of the tectonic collapse of the Alpine orogen.

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A possible new UHP unit in the Western Alps as revealed by ancient Roman quern-stones from Costigliole Saluzzo, Italy

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Keywords: coesite + chloritoid + garnet.

Four quern-stones made on peculiar coesite + chloritoid + garnet ± glaucophane talcschists have been unearthed in the ruins of a villa rustica belonging to the Roman imperial period and located at Costigliole Saluzzo, Western Alps. The site of the villa rustica and the presence of coesite relics could suggest a possible provenance of these rocks from one of the already known ultra-high pressure (UHP) units of the Western Alps, i.e., either the Brossasco-Isasca Unit (BIU) of the southern Dora-Maira Massif or the Lago di Cignana Unit (LCU) of the Piemonte Zermatt-Saas Zone. However, similar talcschists have never been reported from these units. Two samples of coesite-bearing, chloritoid + garnet ± glaucophane talcschist collected from two different specimens of quernstones have been petrologically investigated with the aim of defining their peak pressure–temperature (P-T) conditions. The stability field of the coesite + garnet + talc + chloritoid + glaucophane assemblage has been constrained using isochemical phase diagrams modelled in the MnNCFMASHO system; prograde P-T conditions have been additionally constrained using the yttrium-in-garnet (YAG) geothermometer. Thermodynamic modelling tightly constrains peak P-T conditions at 480–510°C, 27–31 kbar. The unusual Mg-rich composition of the talcschists suggests that they originated by Mg-metasomatism of either a continental crustal protolith (Fe-rich metapelite) or an oceanic crustal protolith (altered oceanic crust). A mechanism similar to that proposed for the well-known pyrope-bearing whiteschists of the UHP BIU, i.e. influx of antigorite-derived fluids along shear zones during subduction, can be envisaged. Although the field occurrence of these coesite + chloritoid + garnet ± glaucophane talcschists is still unknown, the obtained results clearly show that these rocks cannot belong to the UHP BIU, whose peak P-T conditions are at significantly higher T and P (730°C, 40–43 kbar). Therefore, this finding opens the challenging hypothesis of the existence of a further, still unmapped, UHP Unit in the Western Alps that also experienced UHP metamorphism and fluid influx from underlying serpentinites during subduction. A detailed mapping and petrologic investigation of the tectono-metamorphic continental (i.e., southern Dora-Maira Massif) and oceanic (i.e., Monviso meta-ophiolite Complex) units in the proximities of Costigliole Saluzzo is required in order to further constrain the location and the dimension of this new UHP unit.

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Pressure-Temperature-Deformation-Time constraints on the South Tibetan Detachment System along the Alaknanda–Dhauli Ganga valleys, Garhwal Himalaya (N India)

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Keywords: Himalaya metamorphism; in situ geochronology, South Tibetan Detachment System.

The Himalayan belt, extending for over 2400 km, has played a crucial role in shaping our understanding on the exhumation of deep-seated crustal rocks and on the formation of orogenic belt. The Alaknanda-Dhauli Ganga valleys, in the Garhwal Himalaya (N India), offer a complete and well-exposed structural transect of this belt and its metamorphic core (HMC), starting from the Main Central Thrust Zone (MCTZ) up to the South Tibetan Detachment System (STDS) and the Tethyan Sedimentary Sequence (TSS) (*e.g.* Spencer et al., 2012; Jain et al., 2014). Moreover, this area is of key interest for accompanying melt processes, since an undeformed igneous body, the Malari leucogranite with an age of 19 Ma, has been reported to cross-cut the STDS (Sachan et al., 2010).

Detailed field-based, petrographic and microstructural analyses have been carried out. After a careful X-ray mapping and micro-analytical work at the electron microprobe (EPM), the metamorphic evolution of selected samples, has been reconstructed with the aid of P-T-X pseudosection modeling and inverse geothermobarometry. Absolute temporal constraints on the both prograde and exhumation-related tectono-metamorphic history of these samples were obtained with the aid of U-Th-Pb *in situ* monazite geochronology.

In this contribution we focus on the on the STDS-related sheared rocks at the top of HMC. The ductile portion of the STDS affected the top of the HMC migmatite, which experienced peak P-T conditions of c. 10 kbar and ≥ 750°C at ≥ 23.5 Ma. The migmatitic fabric is reworked with the development of a high T sillimanite-bearing mylonitic foliation, temporally constrained at c. 20-18 Ma. Medium T shearing is instead ubiquitous within the Malari leucogranite and sporadically observed in these migmatites associated with greenschist paragenesis. Later brittle structures affected the top of the HMC.

We can demonstrate for the study area that a well preserved ductile to brittle spatial and temporal transition of the STDS-related shearing exists.

Our data, joined with the ones from the geological literature (*e.g.* Thakur et al., 2015 and references therein) shed new insights on the tectono-metamorphic evolution of the Himalayan metamorphic core in this portion of the belt.

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Dating strike-slip motion along the Insubric Fault by detrital zircon U-Pb geochronology

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Keywords: Insubric Fault, Adriatic microplate, Oligocene, Miocene.

The Oligocene-Miocene dynamics of the Adriatic microplate within the Western Mediterranean tectonic puzzle is only partly understood. In fact, although the timing and magnitude of Adriatic slab rollback and backarc extension in the Apennines have long been established, the timing of progressive Adria indentation beneath the Central Alps and of major strike-slip motion along the Insubric Fault are still poorly constrained (Malusà et al., 2015).

Here, we use detrital zircon U-Pb geochronology on foredeep turbidites to track Adria indentation beneath the Central Alps, and provide first time constraints for major strike-slip motion along the Insubric Fault. We compare the geochronologic fingerprints of the exhuming tectonic domes of the Central Alps (Ticino and Toce subdomes) with those of the Oligocene-Miocene turbidites mainly derived from their erosion. Similar to what is observed in modern sands shed from the potential source areas, the analyzed sandstone samples (ranging in age from 32 to 18 Ma) yielded in variable proportions grain ages belonging to Periadriatic, Variscan, Caledonian and Precambrian populations. The ratio between Variscan and Caledonian zircon grains, which are dominant in the Toce and Ticino subdomes, respectively, sharply increases at ~24–23 Ma. This major provenance change may mark the westward shift of the Adriatic indenter beneath the Central Alps, and the associated right-lateral activity of the Insubric Fault (Malusà et al., 2016).

Coexistence of strike-slip motion at the northern boundary of the Adriatic microplate at ~24–23 Ma, and of trench retreat during scissor-type backarc opening to the west, requires a near-vertical rotation axis located at the northern tip of the Ligurian-Provençal basin. We suggest the position of the rotation axis was controlled by the interaction between the European and the Adriatic slabs, which may have collided at depth by the end of the Oligocene triggering the westward shift of the Adriatic indenter beneath the Central Alps.

Malusà M.G., Faccenna C., Baldwin S.L., Fitzgerald P.G., Rossetti F., Balestrieri M.L., Danisik M., Ellero A., Ottria G. & Piromallo C. 2015. Contrasting styles of (U)HP rock exhumation along the Cenozoic Adria-Europe plate boundary (Western Alps, Calabria, Corsica). Geochem. Geophys. Geosyst. 16(6), 1786-1824.

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Ancient or young Apennines? Insights from low-temperature thermochronology in Corsica-Sardinia

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Keywords: northern Tethyan margin, Alpine subduction, Apenninic subduction.

The problematic transition in space and time between the opposite-dipping Alpine and Apenninic subductions, and the inferred southward extension of the Alpine orogenic wedge, have long been a debated issue. The “young-Apennines” hypothesis envisages a Cretaceous-to-Eocene Alpine subduction zone developed across the whole Western Mediterranean, later replaced, after European slab breakoff, by a westward Apenninic subduction developed at the rear of the Alpine wedge since the Oligocene. The “ancient-Apennines” hypothesis envisages, in contrast, two coeval opposite-dipping subduction zones - the Alpine one to the north and the Apenninic one to the south. But there is no general consensus about the location of the northern tip of the Apenninic subduction in Paleogene times, located either in front of Sardinia or in front of Corsica, and on the timing of its northward propagation.

Low-temperature thermochronology data in Corsica-Sardinia may provide useful pin points to shed light on these issues. In fact, according to the ancient-Apennines hypothesis, Sardinia would be located in an upper plate position since the Mesozoic, and may thus preserve the thermochronological imprint acquired by the distal European passive margin during Tethyan rifting. According to the young-Apennines hypothesis, instead, Sardinia would be located in a lower plate position during most of its evolution, and the European distal margin would be no longer preserved because subducted beneath the Adriatic plate.

Our new multi-thermochronologic dataset from Corsica-Sardinia covers the whole Meso-Cenozoic time interval, and fits the theoretical age pattern that is expected in a distal passive margin after continental break-up (Malusà et al., 2016). This indicates that Corsica-Sardinia may represent a fragment of the northern Tethyan margin still preserving the thermochronologic fingerprint acquired during Jurassic rifting. Mesozoic apatite (U-Th)/He ages from crustal sections located close to the Tethyan rift axis (i.e., central-eastern Sardinia) attest that no European continental subduction took place south of Corsica since the Mesozoic. Along the Sardinia transect, post-Jurassic Adria-Europe convergence was possibly accommodated by Adriatic subduction, consistent with the onset of orogenic magmatism. In middle Eocene - Oligocene times, the northward translation of the Adriatic slab beneath the former Tethyan margin induced a coeval northward migration of erosional pulses at the surface, constrained by a trend of progressively decreasing fission track ages from southern Sardinia to NW Corsica. The Adriatic slab reached the Alpine wedge of Corsica by the end of the Oligocene, and started retreating in Neogene times triggering the long-recognized basin opening in the backarc region.

Malusà M.G., Danisik M. & Kuhlemann J. 2016. Tracking the Adriatic-slab travel beneath the Tethyan margin of Corsica–Sardinia by low-temperature thermochronometry. Gondwana Res., 31, 135-149.

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A late Eocene-early Oligocene snapshot of Northern Apennines geodynamics at the Alps/Apennines boundary: structure and kinematics of the Ottone-Levanto Line in Eastern Liguria, Italy

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Keywords: Inclined Transpression, Cataclasites, N Apennine, Ottone-Levanto line, Alpine-Apennine junction.&

In the Northern Apennine, the structural setting is represented by a pile of tectonic units issued from different palogeographic domains during the closure of the Ligure-Piemontese oceanic basin and the following continental collision. The northernmost sector of this belt is of key importance because it represents the junction between the Apennines and the Ligurian Alps. Here the tectonic pile is dissected by several lines, i.e. high-angle shear zones of regional extent, showing different kinematics, age and geodynamic role. Among these lines, the Ottone-Levanto line is regarded in literature as one of the most important structural element that played a key role in the geodynamic evolution of the Northern Apennine-Western Alps boundary.

In this paper, fault rocks exposures representative of the Ottone-Levanto, and cropping out in the Sturla valley of Liguria are described. The field appearance of the Ottone-Levanto line consists of 5 to 15 m shear zone marked by foliated cataclasites, associated with meter thick bodies of unfoliated cataclastic serpentinites. The structural features indicate the predominance of brittle deformation involving components of contraction with top-to-the-NE thrusting and contemporaneous top-to-the-SW sinistral shearing and dip-slip shearing involving components of contraction with top-to-the-NE thrusting and contemporaneous top-to-the-SW sinistral shearing and dip-slip shearing. These structures, that are all broadly contemporaneous, indicates highly heterogeneous, structural patterns that have been mathematically described and modelled as inclined transpression zones by Jones et al. (2004), and that has been described in regions dominated by triclinic transpressional strain (Holdsworth et al., 2002). Moreover, the collected data and the map-scale and regional evidences indicate that the Ottone-Levanto line can be regarded as a sinistral traspressional shear zone developed in the Late Eocene-Early Oligocene time.

A detail review of the previous interpretation of this tectonic line is also presented: the coupling of the data from literature with those from the present study allows correlating the OL line with other lines acting at the Alpine-Apennine junction, such as the Insubric Fault, the Sestri-Voltaggio line and the Central Corsica shear zone, and, consequently, to draw a geodynamic picture of the Western Alps-Apennines boundary in the Late Eocene-Early Oligocene time span. In our interpretation, all these lines developed during collisional tectonics, resulting in both east- and westward thrusting of the internal zone of the Alpine-Apennine system onto the continental margin domains, coeval with the northward displacement of the Adria plate.

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Late Miocene to present extrusion tectonics, subduction and oroclinal bending in the South Caspian Basin and Alborz Mountains (Iran)

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Keywords: Iran, Alborz Mts., South Caspian basin, Oroclinal Bending.

We present results from an extensive paleomagnetic study (76 sites) carried out in the Alborz Mts. (northern Iran), aimed to reconstruct the rotational history and the origin of curvature of this orogenic chain. The analyzed deposits are the sedimentary successions of the Upper Red Formation (Miocene), Lower Red Formation (Oligocene) and Eocene clastic units. Paleomagnetic results indicate that the Alborz Mts. can be considered a secondary arc that originated as a linear mountain belt and progressively acquired its present day curvature through opposite vertical axis rotations occurred along its strike. The curvature of the arc was entirely acquired after middle-late Miocene, which is the age of the youngest investigated sediments (Upper Red Formation). Overall, the obtained paleomagnetic data indicate that the Alborz Mts. can be considered an orocline. Our results allow defining, for the first time, the rotational history of the entire Alborz curved mountain belt, and reconstructing the paleogeographic and tectonic evolution of northern Iran in the framework of the Arabia-Eurasia continental deformation. The kinematics inferred by the pattern of paleomagnetic rotations is at odd with the present day kinematics of northern Iran, characterized by the westward extrusion of South Caspian block, and by a left lateral shear between Central Iran and the central and western sectors of the Alborz Mts. By integrating paleomagnetic data with stratigraphic, thermochronological, structural and GPS information, we propose a new tectonic model for northern Iran. We suggest that the initiation of South Caspian subduction and the activation of westward extrusion of South Caspian block occurred diachronically and that the initiation of the present-day kinematics of northern Iran was quite recent (Lower Pleistocene).

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A revision on the Alps-Apennines relationships: structural signatures and geologic records of interfering orogens

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Keywords: Alps, Apennines.

The relationships between the Alps and the Apennines represent a classical and still debated subject in the regional tectonics of the western Mediterranean (i.e. Argnani, 2012; Carminati et al., 2012; Turco et al., 2012; Vignaroli et al., 2008 and references therein). As a matter of fact, presently, the Alps and the Apennines form two independent and adjacent orogenic segments part of the Alpine Tethys-derived collisional system (Doglioni et al., 1998; Jolivet and Faccenna, 2000; Handy et al., 2010).

They have opposite first order tectonic vergence, W/NW for the Alps, and E/NE for the Apennines, both oriented roughly perpendicular to their arcuate trends. Whereas the tectono-metamorphic history of the exhumed lower plate-derived units of the two belts well tracks their long term subduction frame, the junction area of the two chains (a wide area between the Monferrato and Liguria) is formed by morphologic and tectonic zones characterized by regional structures and geological records result of the kinematically complex space-time interaction between the opposite dipping subductions active in the last 30 Myr (among others Molli et al., 2010; Giacomuzzi et al., 2011; Maino et al., 2013). Moreover, structural relicts of the pre-30 Ma orogenic architecture may be found in Liguria (among others Capponi et al., 2009; D'Atri et al. 2016) and further south in NE Corsica, which has been considered as the prolongation of the Alps (Malavieille and Molli, 2014 and references) or, in a more simplistic view, the inner zone of the Apennines (Principi and Treves, 1985 and following). Using the completely recorded and kinematically well-constrained geological frame of the young Taiwan orogen (Malavieille and Trullenque 2009; Ustaszewski et al. 2012 and references) we provide some general hints which can help to better constrain key aspects of the past evolution of the Alps-Apennines system and, in a more general way, the tectonic signatures for processes of interference between orogens related with opposite-dipping and propagating subduction systems (Molli and Malavieille 2011; Malusà and Garzanti, 2012; Vannucchi and Molli, 2013).

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Strain softening and shear zone localization: an example from the Main Central Thrust in the Mt. Makalu area (Eastern Nepal)

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Keywords: Shear zone, Main Central Thrust, strain softening.

The Main Central Thrust Zone (MCTZ) in Himalaya is one of the largest worldwide shear zones and juxtaposes the medium- to high grade metamorphic rocks of the Greater Himalaya Sequence structurally above the low to medium-grade metamorphic rocks of the Lesser Himalaya Sequence. We investigate the processes active during the MCTZ evolution in the Makalu area (Eastern Nepal) where Precambrian orthogneiss are ductilely sheared and structural analysis testifies how a progressive transformation from orthogneiss to micaschist, through a transitional zone, is present.

Quantitative textural evolution, bulk-rock major and trace element chemical changes and mineral phases chemical changes have been characterized studying representative samples from "pristine" orthogneiss, transitional zone and micaschist.

Kinematic indicators point to a top-to-the-south sense of shear. They are represented by S-C fabric, rotated porphyroclasts and mica fishes. Kinematic indicators are progressively much more developed associated with changes of foliation morphology (from a spaced anastomosing schistosity to a continuous) starting from orthogneiss to micaschist.

ICP-MS trace elements data confirm the common protolith origin for both the orthogneiss and the micaschist.

EPMA studies show a definite increase of phengitic substitution in muscovite, and a change in biotite composition, going from gneiss to micaschist, from Al-high annite to Al-low content phlogopite.

Tourmaline in gneiss can be classified as schorlites, with Y crystallographic site fully occupied, and their chemical variability is described by the common $(Mg+Fe)^{2+} + X^{+} \longleftrightarrow Al^{3+} + \square$ coupled substitution. They are fairly homogeneous, rarely showing thin Fe-rich rims.

Tourmalines in micaschist show a sharp zoning, with schorlitic cores, quite similar to tourmaline found in gneisses. Rims have dravitic compositions, with the X site almost fully occupied and a lower total for Y crystallographic site, pointing to the presence of some Li^{+}, accommodated according to the substitution $2Mg^{2+} \longleftrightarrow Li^{+} + Al^{3+}$.

Quantitative modal phase variations have been investigated with image analysis techniques (on BSE-SEM images) pointing to a progressive disappearance of feldspars balanced by increasing of micas.

This latter process is assisted by progressive increase of Mg content in white micas, by the transition from annite to phlogopite, and the crystallization of dravitic rims in tourmalines.

Microstructural and geochemical analyses support a non-isochemical process of strain softening related to phase transformation from gneiss to micaschist enhanced by fluids infiltration and Mg metasomatism, which progressively favoured the localization of the non-coaxial deformation within the MCTZ.

Tectonic and metamorphic discontinuities in the Greater Himalayan Sequence in Central Himalaya: new perspectives for exhumation models

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Keywords: Greater Himalayan Sequence, shear zone, exhumation, Himalaya.

The Greater Himalayan Sequence (GHS), the main metamorphic unit of the Himalayas, has been till now regarded as a coherent tectonic unit bounded to the South by the Main Central Thrust (MCT) and to the North by the South Tibetan Detachment (STD) whose contemporanous activity controlled its exhumation between 23 and 17 Ma.

In the past several shear zones have been recognized within the GHS but they have been regarded as out of sequence thrusts. Recent investigations, using a multitecniques approach, in Central Himalaya allowed to recognize a tectonic and metamorphic discontinuity, localized in between the MCT and the STDS, with a top-to-the SW sense of shear (Higher Himalayan Discontinuity: HHD) (Montomoli et al., 2013).

U-(Th)-Pb in situ monazite ages provide temporal constraint of HHD initiation at 27-25 Ma, older than the MCT, and continuing up to 18-17 Ma.

A comparison between the HHD and other discontinuities recognized along the belt highlights many similarities so that it can be considered a regional tectonic feature running for more than 700 km (Montomoli et al. 2015, Wang et al., 2016).

In Central Nepal the occurrence of a structurally higher contractional shear zone in the GHS (above the HHD), the Kalopani shear zone, active from 41 to 28 Ma (U-Th-Pb on monazite) points out to an even more complex deformation pattern characterized by in sequence shearing starting from Late Eocene.

The actual proposed models of exhumation of the GHS, based on the MCT and STD contemporaneous activities, are not able to explain the occurrence in-sequence shear zones and any model should account for the occurrence of the tectonic and metamorphic discontinuities within the GHS and its consequences on the metamorphic paths and on the assembly of Himalayan belt.

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Geological mapping and stratigraphic-structural study of the left side of the middle Valle Stura di Demonte (Colle Valcavera-Colle Servagno, CN)

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Keywords: geological mapping, stratigraphy, structural geology, Valle Stura di Demonte, Piemonte.

A geological study of an area placed on the left side of the Stura di Demonte valley (CN), between Colle di Valcavera (E-SE) and Colle Servagno (W-NW) was performed.

The main objectives of the work were: studying the tectono-stratigraphic setting; analyzing the stratigraphic succession (facies analysis) to define the paleogeographic pertinence of the tectonic units; performing structural analysis with the purpose of reconstructing the structural evolution and putting it in the regional framework; individuating and describing the stratigraphic and sedimentological evidence of syn-sedimentary pre-Alpine tectonics.

The work consisted of geological mapping at 1:10.000 scale over a 30 km^2 extended area, optical microscope and cathodoluminescence analysis of 45 thin section, and the analysis of meso and macroscale structural data.

The results are: the attribution to the Dauphinois s.l. domain of the main geological unit of the study area, the Giordano-Savi Unit, that has been split into two geometrical sub-units on the base of their different structural setting: the Mt. Salè Unit attributed to the Provençal paleogeographic domain and Mt. Giordano-C.ma Piconiera Unit attributed to the Dauphinois s.s. paleogeographic domain. This interpretation is in contrast with the old one that gave to the Giordano-Savi Unit a Subbriançonaise pertinence.

Macro and mesoscale structures can be referred to two distinct deformative stages F1 and F2. The F1 stage is interpreted in a regional left-lateral transpressive system, followed by a phase (F2) of tectonic dislocation by individual poorly interconneted faults.

The study area was controlled by, previously unknown, syn-sedimentary tectonics, active during Late Jurassic-Early Cretaceous and during Eocene. A large (3 km extended) paleoescarpement, called Colle Serur Paleoescarpement (CSP), was recognised, which was attributed to the activity of a pre-Alpine fault during the Late Jurassic-Early Cretaceous. Pre-Alpine faults seem to have carried large amount of hydrothermal fluids, as indicated by extended evidence of dolomitization, recognised in the Triassic-Jurassic successions of the mapped area.

Finally, it was possible to reconstruct, in broad terms, the middle Eocene paleotectonic framework, presumably characterized by extensional structures, not still preserved, inducing the exposure and subsequent erosion of the Briançonnais succession and the deposition of the Eocene foreland basin succession directly on Middle Triassic dolostone.

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Tethyan heritage during orogenic development of the Apennine-Adriatic thrust belt-foreland system, Central Italy

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Keywords: Tethyan heritage, Apennine-Adriatic system, positive structural inversion.

Orogenic systems that formed at the expenses of rifted margins belonging to the Tethyan realm usually exhibit the signature of inherited extensional structures within thrust belts. The interaction of early extensional with subsequent compressional deformations leads to positive inversion tectonics resulting in composite, often complex structures. The recognition of positive inversion in the outer zones of orogenic provinces and in their adjacent foreland domains makes it possible to unravel the deformation history, to infer the tectonic style and to evaluate the hydrocarbon potential of investigated thrust belts. The Apennine-Adriatic thrust belt-foreland system of central Italy provides a unique scenario to establish concepts of Tethyan heritage and tectonic inversion, due to the possibility to draw a straightforward comparison between structures exposed in the outcropping parts of the thrust belt with those located in the buried parts of the mildly deformed foreland. Inversion structures from the Apennine-Adriatic thrust belt-foreland system are here investigated and compared in order to reconstruct their styles and define their tectonic significance. The final aim is to put some constraints on a more regional context and to provide some insights for reassessing hydrocarbon prospectivity in these regions.

Individual structures are reconstructed within the central sector of the outer Apennine carbonate-dominated thrust belt. Contrasting styles of inversion, resulting from the Pliocene-Quaternary selective reactivation of Tethyan rift faults (transpressional reactivation or "shortcut" thrust propagation), characterize the differently-oriented oblique and frontal thrust ramps resulting in curved thrust systems. They are associated with various thrust-related folding mechanisms giving rise to coexisting and laterally changing fault-bend, fault-propagation and push-up fold structures. By taking advantage of recently-reprocessed seismic data from the Italian Adriatic Sea, inversion structures are also investigated in the deformed foreland. In this area, the compressive deformation is mild and basin inversion is promoted resulting in different structures along various structural trends. Pulses of inversion occurs repeatedly over the Cretaceous-Tertiary time interval and are coeval with the emplacement of the surrounding thrust belts. The characteristics of the Adriatic foreland structures are typical of intraplate deformational settings.

Collectively, the structural reconstructions here presented reveal that the Tethyan heritage of rift faults plays a significant role during the evolution of the Apennine-Adriatic thrust belt-foreland system. This revisited concept provides some important constraints on reconstructing the styles of contractional deformation and creates different scenarios for reassessing hydrocarbon prospectivity.

Paleomagnetism of the Gaoligong strike-slip fault zone (Yunnan, China): understanding block rotation pattern

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Keywords: Paleomagnetism, Yunnan, China, block rotation, strike-slip fault zone.

Continental Asia SE of the Eastern Himalayan Syntaxis is a zone of SE-ward escape characterized since early Tertiary times by a clockwise rotation and crustal flow around the northern edge of India (Tapponnier et al., 1982). The SE-ward directed crustal drift is accommodated by major strike-slip shear zones, which bound elongated continental blocks. In western Yunnan, from west to east three main tectonic blocks (called Tengchong, Baoshan, and Lanping–Simao blocks) are separated by the Gaoligong, Biluoxueshan–Chongshan, and Ailaoshan–Red River shear zones, respectively. The Cenozoic (late Paleogene-Neogene) tectonic deformation and kinematics along these major active strike-slip faults is fairly well understood (e.g. Zhang et al., 2010; 2012), whereas several uncertainties remain on the post-15 Ma and active deformation.

Here we report on new paleomagnetic data from Tengchong and Baoshan blocks, at both edges of the Gaoligong dextral strike-slip fault zone. We paleomagnetically sampled 50 sites (ca. 500 oriented samples) from Jurassic-Tertiary red beds, Plio-Pleistocene lava flows and Pliocene whitish lacustrine silts located within a maximum distance of 20 km from the fault. Such distance is established considering that several studies demonstrated that shear-related rotations virtually end within 10–20 km from fault trace (Hernandez-Moreno et al., 2014 and references therein). The paleomagnetic samples were collected using a petrol-powered portable drill cooled by water and oriented in situ using the Sun (when possible) and a magnetic compass. Paleomagnetic measurements were carried out in the shielded room of the paleomagnetic laboratory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Rome), using a 2G Enterprises DC-superconducting quantum interference device cryogenic magnetometer. Although the measurements are still in progress, the results already available contribute significantly to understand the pattern of deformation and vertical axis rotations along the Gaoligong fault zone, and to assess quantitatively rigid block rotation vs. rotations due to fault displacement occurring during Tertiary and Plio-Pleistocene times.

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Deciphering the geodynamic evolution of Large Hot Orogens; insight from numerical modeling

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Keywords: Numerical Modeling, Hot Orogens, Exhumation, P-T-t Path.

The development of the collisional orogens depends on the initial thermal state, radiogenic heat production, convergent rate and mechanical property of the crustal units (Faccenda et al., 2008). In particular, the strength of the crustal unit is a paramount parameter that controls the thickness of the orogenetic crust that, in conjunction with radiogenic heat production, controls the thermal state of the collisional belt (Beaumont et al., 2006).

In the work herein presented, we investigate the role of the upper crust rheology on the evolution of the orogens, in order to reproduce the suitable conditions for the emergence of the large hot orogens (e.g. Himalaya). We performed several numerical experiments, using I2VIS, a petro-thermo-mechanical numerical code (Gerya and Yuen, 2003), in which we systematically changed the strength of the upper crust of the lower and upper plate (L.P. and U.P.) by varying the pre-exponential factor of the viscous creep flaw law (Wet Quarzite, Ranalli, 1995). The results of our numerical experiment give several insights: 1) the strength of the crust of the lower plate is a paramount parameters for the burial, thickening and exhumation processes; if the crust is unable to sustain the large stress arising from the collision, it undergoes a wider, pure shear deformation, blocking the under-thrusting processes: the temperature achieved by the system is low, and the high grade metamorphic rocks do not exhume; 2) the strength of the crust of the upper plate controls the plate yielding. If the upper plate does not yield, the material flux from the lower plate is blocked, and it accumulates near the suture zone. The result is an asymmetric orogen in which the deformation propagates toward L.P. foreland; otherwise, the results is a symmetric orogenetic system in which the deformation propagates toward the U.P. foreland.

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K-rich magmatism in extensional settings: the Oligocene-lower Miocene Evros volcanic rocks from north-eastern Greece (Thrace)

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Keywords: extensional magmatism, Evros volcanics, geochemistry, Sr-Nd-Pb isotopes.

The Evros Volcanic Rocks (EVR) crop out in northeastern Greece (Thrace) mostly in eastern Hellenic Rhodope Massif and Circum Rhodope Belt. Magmatism in the Rhodope Massif is the result of convergence between Eurasian and African plates since Late Cretaceous. Three distinctive magmatic events related with subduction can be recognised in the Rhodope Massif: i) a Late Cretaceous subduction related, ii) an Early-Middle Eocene post-collisional, and iii) a Late Eocene- Miocene extensional. The EVR belong to the late Eocene-Miocene magmatic event and, based on K/Ar geochronology, two main periods of volcanic activity, an Oligocene (33.5-25.4 Ma) and a Lower Miocene (22.0-19.6 Ma) can be broadly distinguished. Previous geochemical investigations (Christofides et al., 2004, 2013, Pinarelli et al., 2015) are discussed along with new geochemical and isotope (Sr, Nd, and Pb) data carried out in the framework of the present work.

The EVR are calc-alkaline with medium- to high-K character, and range in composition from basaltic andesite to rhyolite. Despite some dispersion, the volcanic rocks display positive trends of Rb, La, Hf, Ta, Pb, Th, negative trends of V, Sr, and Sc, and bell-shaped patterns of Zr and Ba in the Harker's plots. However, the mafic rocks have trends with different slopes when compared to those of intermediate-acidic rocks. Basaltic andesites with MgO contents >4.0% display incompatible element patterns with enrichment of Large Ion Lithophile Elements (LILE) and depletion of High Field Strength Elements (HFS), negative spikes of Nb, P, Ti, and positive spike of Pb, tightly resembling the patterns of volcanic arc magmas. Sr-Nd-Pb isotopes vary largely in the EVR: (87Sr/86Sr)i = 0.70531-0.70832, (143Nd/144Nd)i = 0.51235-0.51260, (206Pb/204Pb)i = 18.178-18.708, (207Pb/204Pb)i = 15.605-15.686, (208Pb/204Pb)i = 38.119-38.869. They display well-defined negative correlations between (143Nd/144Nd)i vs. (87Sr/86Sr)i and (206Pb/204Pb)i vs. (87Sr/86Sr)i, and positive correlation between (143Nd/144Nd)i vs. (206Pb/204Pb)i. By contrast, no correlations are evident between isotope ratios and geochemical parameters, suggesting independent processes controlling isotope vs. chemical evolution. Overall, the Oligocene volcanics show a marked decrease of (87Sr/86Sr)i and increase of (143Nd/144Nd)i with time, whereas the lower Miocene rocks display opposite distribution. Lead isotope variations are more complex: in the older group (206Pb/204Pb)i increases with time whereas (207Pb/204Pb)i decreases, and vice versa in the younger group. (208Pb/204Pb)i does not show defined correlations with time. Consequently, a change in the magmatic feeding system can be inferred after about 25 Ma, due to either arrival of magma from deep, or tapping different levels of the magmatic apparatus.

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The northward tectonic transport in the southern Apennines: examples from the Capri Island and western Sorrento Peninsula (Italy)

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Keywords: thrust fault system, Sorrento Peninsula, Capri Island, southern Italy.

We analyzed a thrust fault system located in the western Sorrento Peninsula and Capri Island (southern Italy) where several mesoscale structures related to the main thrusts, such as Riedel shear planes, overturned folds, minor thrust and back-thrust faults, suggest a dominant northward tectonic transport (Vitale et al., 2016). Major and minor thrust faults, generally characterized by a ramp-flat geometry, involved the Mesozoic Apennine carbonates, the Middle Miocene foredeep, and the unconformable thrust-top basin deposits. The biostratigraphic analysis of calcareous nannoplankton assemblages on the thrust-top basin sediments indicates an age not older than late Tortonian. We propose that this out of-sequence thrusting stage was related to a regional tectonic event widespread in the entire southern Apennines, probably occurred in the Pliocene time simultaneously with the activity of deep-seated thrust faults that involved the buried carbonates of the Apulian platform. These out of-sequence thrust faults, here referred to as “envelopment thrusts,” were enucleated in a lower structural level with respect to the allochthonous wedge, representing the W–E segments of large regional arcuate structures.

Vitale S., Tramparulo F. d.A., Ciarcia S., Amore F.O., Prinzi E.P. & Laiena F. 2016. The northward tectonic transport in the southern Apennines: Examples from the Capri Island and western Sorrento Peninsula (Italy). International Journal of Earth Sciences.

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Tectono-metamorphic architecture and evolution of the Greater Himalayan Sequence in the Gosainkund-Helambu region (central Nepal Himalaya): a field-based and petrologic study

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Keywords: Himalaya, P-T path, Greater Himalayan Sequence, pseudosection modelling, tectono-metamorphic arch

Although poorly studied (Rai et al., 1998), the Gosainkund-Helambu region in central Nepal occupies a key area for the development of Himalayan kinematic models, connecting the well-investigated Langtang area to the north with the Kathmandu Nappe (KN) to the south. In order to understand the structural and metamorphic architecture of the Greater Himalayan Sequence (GHS) in this region, field-based and petrological studies were performed, focusing on metapelite samples from both transects.

Along the Langtang section, two tectono-metamorphic units have been distinguished within the GHS, separated by a metamorphic discontinuity (already defined by Kohn, 2008): the Lower-Greater Himalayan Sequence (L-GHS), characterized by peak P-T conditions at 720°C, 9.8 kbar (corresponding to a T-gradient of about 22°C/km), and the structurally higher Upper-Greater Himalayan Sequence (U-GHS), with peak metamorphic conditions at 760-810°C, < 9 kbar (corresponding to a temperature gradient of about 27°C/km). The results of petrological modelling on the metapelites from the Gosainkund-Helambu section show that this region is entirely carved within a structurally sub-horizontal and relatively thin L-GHS: the estimated peak metamorphic conditions slightly increase from the lower to the upper structural levels, from ca. 735°C, 10 kbar to ca. 750°C, 10.5 kbar, corresponding to a uniform T-gradient of 22°C/km, consistent with that recorded by the L-GHS samples from the Langtang section.

These results have significant implications for the interpretation of the KN and provide a contribution to the more general discussion of the Himalayan kinematic models. The structurally lower unit of the KN can be correlated to the L-GHS; this result supports those models that correlate the KN to the Tethyan Sedimentary Sequence and that suggest the merging of the South Tibetan Detachment System and the Main Central Thrust on the northern side of the KN. In this sector of the Himalayan chain the most appropriate kinematic model able to explain the observed tectono-metamorphic architecture of the GHS is the duplexing model (Webb et al., 2013) or hybrid models (e.g. duplexing + tectonic wedge model; He et al., 2015).

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A tilted Permian middle crust affected by thermal and rifting events: the case of the Dervio-Olgiasca Zone (Southern Alps, Italy)

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Keywords: Passive Margin, Tectono-Termal Evolution, Structural Geology, Metamorphism, Southern Alps.

The fossil rifted margin of the Adriatic plate is exposed at the surface due to Alpine shortening. It provides an exceptional opportunity to investigate the tectono-thermal evolution of the margin before the continental break-up. South of the Insubric line, continental slices of basement are not affected by Alpine metamorphism and possibly show the original metamorphic imprint generated by rifting phases.

The Dervio-Olgiasca Zone (DOZ) situated in the northern part of the Como lake, south of the Insubric line, is a slice of Variscan basement recording a polymetamorphic history from Carboniferous to Early Jurassic (e.g. Spalla et al., 2000). The DOZ is limited to the south and east by the Lugano-Val Grande Fault, a Jurassic normal fault which exhumed the deeper crustal basement (Bertotti et al., 1999), and in the north by the Alpine Musso line.

The DOZ represents a well-preserved portion of the Permian middle crust, consisting mainly of micaschists and amphibolites, rotated to a vertical position. In the DOZ, a Barrovian metamorphic field gradient is recorded from Chl+Ab mineral assemblages to the south, to Ms+Bt+Grt+Sil mineral assemblages to the north. Pegmatitic dykes occur only in the higher grade portion of the DOZ. Two main foliations, at high angle to each other, often occur. The older foliation (S1) is interpreted to be Variscan (e.g. Spalla et al., 2000) whereas the younger, prominent one (S2) is related to a vertical shortening affecting the previous steeply dipping foliation. The occurrence of stretched pegmatitic dykes, dated at 226 +/- 2 Ma (Sanders et al., 1996), could suggest a Triassic deformation event.

The higher grade portion of the DOZ records a tectono-metamorphic evolution with a syn-to post-main-foliation (S2) thermal event. It is more complex than previously reported and could better constrain the late to post-Variscan evolution of the Adriatic continental crust.

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Activation of the ductile shearing along the Gediz detachment, Menderes Massif core complex (western Turkey)

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Keywords: crustal extension, ductile shearing, U-Pb geochronology, Menderes Massif, Turkey.

The Menderes Massif of western Turkey is a key area to study feedback relationships between Neogene magma generation/emplacement and activation of extensional detachment tectonics. Here, we present new textural analysis and in situ U-(Th)-Pb titanite dating from selected samples collected in the transition from the undeformed to the mylonitized zones of the Miocene Salihli granodiorite at the footwall of the ductile-to-brittle, top-to-the-NNE Gediz detachment. Ductile shearing was accompanied by the fluid-mediated sub-solidus transformation of the granodiorite to orthogneiss, which occurred at shallower crustal levels and temperatures compatible with the upper greenschist-to-amphibolite facies metamorphic conditions (550-630 °C and P<0.2 GPa). The syn-tectonics metamorphic overgrowth of REE-poor titanite on pristine REE-rich igneous titanite offers the possibility to constrain the timing of magma crystallisation and solid-state shearing at the footwall of the Gediz detachment. The spread of $^{206}Pb^{*}/^{238}U$ ages and the REE re-distribution in titanite that spatially correlates with the Th/U zoning suggests that titanite was affected by radiogenic Pb diffusion and predominantly preserves open-system ages during fluid-assisted syn-tectonic re-crystallisation in the transition from magma crystallization and emplacement (at ~17 Ma) to the syn-tectonic, solid-state shearing (at ca. 14 Ma). A time lapse of ca. 3 Ma is then documented between the crustal emplacement of the Salihli granodiorite and activation of the ductile extensional shearing along the Gediz detachment. The reconstruction of the cooling history of the Salihli granodiorite documents a punctuated evolution dominated by two episodes of rapid cooling (~100 °C/Ma) constrained between ~17 Ma and ~12 Ma and between ~3 Ma and ~2 Ma. We relate the first episode to post-emplacement activation of ductile shearing and the second episode to brittle high-angle faulting, respectively. Our dataset suggests that in the Menderes Massif the activation of ductile extension leading to core-complex formation was a consequence, rather than the cause, of magma emplacement in the extending crust.

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The influence of inversion tectonics in the building of minor arcuate shapes: An example from the Northern Apennines

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Keywords: Northern Apennines, inversion tectonics, tectonic rotations, arcs.

Arcuate fold-and-thrust belts have been extensively studied in the literature, but few attentions have been paid to minor arcuate structures. Nevertheless, the detailed investigation of small arcuate structures hosted in major arcs could contribute to understand pervasiveness of the deformation mechanism. The integration of paleomagnetic and structural data has been proved to be essential for understanding the kinematics of arcuate structures, and particularly the influence of inversion tectonics. We performed a structural and paleomagnetic analysis on one of the inner minor arcs of the Northern Apennines, showing an arcuate shape concentric to the inner regional arcuate front of the northern Apennines ridge: the Valnerina - M. Primo fold-and-thrust structure. It is characterized by a series of NE-to-E-verging folds with gentle backlimbs and vertical to slightly overturned forelimbs, describing a change in structural strike at the kilometric scale. The orientation of the individual thrusts and folds ranges between NW-SE in frontal ramps and N-S in lateral ramps.

The paleomagnetic analysis from 18 retained sites shows similar tectonic rotations, not correlated to the local structural trend from which they have been collected. Thus, the strike changes of the fold axial trend observed in the study area are primary features controlled by the inheritance of pre-orogenic discontinuities on thrust and related folds development.

Structural data and a geological cross-section show that NS-trending anticlines and NW–SE-trending anticlines represent fault-propagation shortcut anticlines and fault-bend reactivation folds, respectively, developed in an inversion tectonics context (Calamita et al., 2012).

This study points out once again the influence of the inversion tectonics in the building of the Apennine chain, and its scale invariance. In the studied minor arc, tectonic rotations have been induced during the orogenesis, accentuating a pre-existent arcuate shape, with a mechanism similar to the one documented at the scale of the regional Northern Apennines arcuate fold-and-thrust belt (e.g., Cifelli & Mattei, 2010; Satolli & Calamita, 2012).

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Plio-Quaternary development of the Sangro-Volturno cross-strike discontinuity (Central Apennines, Italy)

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Keywords: Cross-strike faults, Oblique thrust ramps, Inversion tectonics, Central Apennines.

Cross-strike discontinuities, oblique to the main thrust belt trend, mark lateral changes in the outcropping structural levels (e.g., Apotria, 1995). Their occurrence strongly suggests that the thrust system architecture has likely been influenced by inherited extensional fault patterns (e.g., Paulsen & Marshak 1999).

The NNE-SSW-trending Sangro-Volturno oblique thrust (SVOTR), representing the outer thrust front of the Pliocene–Quaternary foreland thrust system, is a remarkable example of a main cross-strike discontinuity from the Central Apennines. It marks dramatic lateral changes in tectonic style, topography, structural and stratigraphic features between the Central and the Southern Apennines.

Geological and structural data integrated with seismic reflection profiles and low-temperature thermochronometers allowed defining the role of this major cross-strike discontinuity during the kinematic evolution of the Central Apennine foreland thrust belt (Satolli et al., 2014). The location and development of the SVOTR have been influenced by inherited extensional faults within a positive inversion tectonics context. In fact, its thrust-related structures breache the allochthonous units, postdating their emplacement and being consistent with an in-sequence forelandward thrust propagation. Furthermore, the regional distribution of the maximum paleotemperature values across the SVOTR document an original distribution of the allochthonous Ligurian units extending over both its hanging-wall and footwall blocks.

Oblique thrusting on high-angle faults associated with the transpressive reactivation of pre-existing normal faults caused the strong hanging-wall uplift, that brought both to the axial culmination of the Central Apennines and the complete unroofing of the allochthonous Ligurian units, leading to the exhumation of Adria units in the Central Apennines.

The example of the SVOTR in the Apennines provides a valuable example for understanding the effect of inversion-related oblique thrust ramps on the development of structural geometries, axial culminations, and exhumation events. In foreland thrust belts, involved in positive inversion tectonics, cross-strike discontinuities are most likely to be oblique thrust ramps that reactivated precursor extensional faults.

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Understanding paleomagnetic rotations in Sicily: Thrust vs. transpressive structures

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Keywords: paleomagnetic rotations, thrust tectonics, transpressive faults, Sicily.

Since the 1970s, paleomagnetic data collected in Sicily have documented large magnitude clockwise (CW) rotations around vertical axis with respect to Africa and the Hyblean foreland. Many Authors argued that rotations arise from rotational thrusting of large coherent nappes coinciding with paleogeographic units. In the forward thrust propagation process, each nappe rotates the overlying nappe stack. This would explain the stepwise decrease of rotation magnitudes from the internal Panormide unit (90°-140°) to the external Saccense unit, yielding no rotation. However, other Authors later proposed that rotations of Sicily are the consequence of dextral shear occurring since late Miocene times along E-W to NW-SE strike-slip faults.

To understand the tectonics responsible of paleomagnetic rotations in Sicily, we paleomagnetically investigated 29 sites and a stratigraphic section from Meso-Cenozoic sediments belonging to the Imerese and Trapanese successions exposed in the Piana degli Albanesi area, Mt. Kumeta, and Rocca Busambra. In the study area the fold and thrust belt is characterized by the occurrence of two main sets of subsequent tectonic structures: 1) the early thrusts, producing imbricate-fan and duplex since early Tortonian (deep-water Imerese Units thrust over carbonate-platform Trapanese units); 2) the superimposed wedging at depth of carbonate platform units (since late Tortonian), that produced the most striking (and studied) structural highs of Kumeta and Busambra ridges, bounded by transpressive faults.

In order to test the effect of the latter faults on the cumulated CW rotation, we collected data along several transects perpendicular to both Kumeta and Busambra ridges. In fact, rotations are expected to diminish progressively moving away from faults located at the northern ridge edges, in a way that is related to fault offset.

The main results of our study are as follows:

1. Six new sites (and one site from previous study) show that the Imerese unit rotated ≈130°, similarly to the Panormide unit at the Monti di Palermo. This evidence requires updated discussion on the tectonic and paleogeographic relations between the Panormide and Imerese domains.
2. At Mt. Kumeta the rotations are effectively greater (120°) along the dextral fault plane, but they decrease to 80° (normal value of the Trapanese unit) at only 300-400 m from the fault. Thus we calculate that the lateral offset of the Kumeta transpressive fault is definitely less than 1 km.
3. At both Mt. Kumeta and Rocca Busambra, rotations from Scaglia sites surprisingly increase moving southward (i.e. far from fault). This suggests a differential rotational and tectonic behavior of the Scaglia with respect to the underlying carbonate backbones of the Trapanese ridges.

As a conclusion, paleomagnetic rotations in Sicily are almost entirely due to thrust tectonics, while transpressive fault activity induced local rotations that fade out at only few hundreds of meters from fault planes.

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Extensive backthrusting features in the northern Sicily continental margin highlight a late collisional stage of the Sicilian Fold and Thrust Belt

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Keywords: backthrusting, late collisional stage, Sicilan Fold and Thrust Belt, subduction polarity.

Backthrusting, nappe refolding, and normal faulting frequently characterize late collisional stage of an orogen. Shortening driven by backthrusting is widely reported in the Alpine orogen, and it has been proposed to be responsible for the increase of subsidence. Moreover delamination and backthrusting has been considered as related to subcritical condition of a Coulomb-type accretional wedge (Torres Carbonell et al., 2011).

The Sicilian Fold and Thrust Belt (SFTB) was characterized by a three-stage evolution during the last 15 My: two main shortening events generated and developed at different structural levels (shallow- and deep-seated thrusts in thin-skinned thrust-model) and different time intervals, involving mainly the Meso-Cenozoic carbonate units of the ancient African passive continental margin, followed by a more recent thick-skinned thrust-model involving the Plio-Pleistiocene deposits in the frontal area as well as the crystalline basement in the internal sector of the chain.

We investigated the northern Sicily continental margin, by using differently-penetrative seismic reflection data, including a deep crustal profile, calibrated with detailed field surveys and borehole data. On the whole, the tectonic edifice appears to be interested, both offshore and onshore, by a peculiar structural style that can be interpreted as a triangle zone bounded, on the southern side by N-dipping high-angle transpressional faults (e.g. Busambra fault), mainly Early Pliocene to Early Pleistocene in age, and on its northern side, by high-angle S-dipping thrusts (e.g. Kumeta fault), deeply connected with a low-angle décollement layer. In the outer sector of the SFTB, double-verging structures (with NW and SE-tectonic transport) have been described for the Plio-Pleistocene evolution of the Gela Thrust System. The southern Tyrrhenian region is also interested by normal faulting and subsidence (e.g. Cefalù basin), delamination processes, and widespread deep seismicity.

A late Miocene-Quaternary northern migration of the plate margin producing opposite-verging structures is reported in the northern Africa plate boundary (e.g. NW Algeria Neogene margin; Mauffret, 2007). A plate boundary reorganization during the latest 0.8–0.5 My with the development of backthrusts have been documented in the Mediterranean region (Goes et al., 2004).

Our hypothesis is that the most recent tectonic processes in the study region are representative of a late collisional stage in the northern Sicily mountain building and at a larger scale could be a precursor of a change in the subduction polarity in the central belt of Mediterranean, as a consequence of the ongoing collision of the African promontory with the thinned continental to oceanic sectors (Algerian and Tyrrhenian basins) of the European plate.

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Cenozoic tectonic evolution of the Rif chain: new data from the Jebha area (Morocco)

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Keywords: structural analysis, tectonics, shear bands, Miocene, Jebha Fault.

The Jebha area is a key sector to understand the orogenic evolution of the Rif chain in Morocco (Vitale et al., 2015). This sector, located in the Central sector of this orogenic belt, is characterized by the occurrence of the left lateral Jebha-Chrafate transfer fault that allowed, in the Miocene time, the westward migration of the internal thrust front. The geological and structural survey of the area revealed a tectonic history characterized at least by five deformation stages, spanning in age between the Eocene and Miocene.

The first orogenic pulse produced the tectonic stacking of the Ghomaride thrust sheets. During the late Aquitanian and Langhian, the imbrication of several Internal Dorsale Calcaire slices occurred, under a dominant ENE-WSW shortening. In Burdigalian time an orogenic stage, characterized by a main SE tectonic transport, allowed the External Dorsale Calcaire to overthrust the Maghrebian Flysch Basin Units by means of a dominant thin-skinned tectonics. An out-of-sequence thrusting stage involved the Ghomaride and Dorsale Calcaire units synchronously with the buttressing following the collision of the allochthonous wedge against the External Rif domain. The latter produces a general back-thrusting which deformed the entire tectonic pile. A NE-SW shortening occurred in the Langhian-Serravallian time produced strike-slip faults and SW-verging folds and finally a radial extension affected the whole chain.

Vitale S., Zaghloul M.N., El Ouaragli B., Tramparulo F.D.A. & Ciarcia S. 2015. Polyphase deformation of the Dorsale Calcaire Complex and the Maghrebian Flysch Basin Units in the Jebha area (Central Rif, Morocco): New insights into the Miocene tectonic evolution of the Central Rif belt. Journal of Geodynamics, 90, 14-31.

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The Cretaceous-Paleogene Abortive Rift in the southern Adria domain (southern Apennines, Italy)

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Keywords: rifting, extension, bauxites, scaglia, anorogenic magmatism, nannoplakton analysis.

This study provides new data and a reappraisal of the literature concerning the uppermost Cretaceous-Paleogene stratigraphy, biostratigraphy, tectonics and magmatism in the southern Apennines, with the aim of demonstrating the occurrence of an Albian to Paleogene abortive rifting stage in the southern Adria domain. This interval marks an important discontinuity in the tectono-stratigraphic evolution primarily recorded by coeval uplift and drowning of different sectors of the Apennine and Apulian Platforms, which locally produced a change in the paleoenvironment, from shallow-water platform to slope and basin facies deposits or the development of thick bauxitic levels. Contemporaneously, in the surrounding basins a large amount of calciclastic sediments was deposited, testifying for an increased sediment supply from the emerging sectors of the carbonate platforms. This time interval was also characterized by the occurrence of anorogenic magmatism and syn-sedimentary extensional faulting that, together with the changed sedimentary facies distribution, point out for a crustal-scale extensional tectonics. Timing, distance from the actively growing eastern Alps and, above all, orientation of extensional structures and synchronous anorogenic magmatism poorly fit with a peripheral bulge stage related with the first pulses of the Alpine collision. We propose an alternative model where such an event is the result of a rifting episode, characterized by limited anorogenic magmatism, starting in the Albian and reaching its climax in the uppermost Cretaceous-Eocene times. In the proposed tectonic scenario the extensional tectonics recorded in several sectors of the Adria domain was synchronous with that affecting the Hyblean (Sicily), Pelagian (Tunisia) and Sirte Basin Province Rift (Libya) to the south and was part of a single abortive rift system, which extended from the Sirte Basin up to the southern margin of the Thetyan Ocean to the NW.

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The Cimmerian obduction of the Bashgumbaz ophiolites (South Pamir, Tajikistan)

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Keywords: Pamirs, Cimmerian orogeny, Bashgumbaz ophiolites.

The Pamir belts, located NW of the Himalaya, formed in response to the Cenozoic collision and indentation of India with Eurasia resulting in strong deformation and bending of pre-existing Paleozoic to Mesozoic orogens. Several crustal blocks separated by complex and scarcely studied suture zones form the present day tectonic architecture of the Pamirs. The extreme crustal shortening experienced by the Pamirs during the indentation of India hinders straightforward correlations between tectonic terranes of the Himalaya-Tibetan area with their potential continuations through the Pamirs into Afghanistan and Iran.

Existing stratigraphic and paleontological data suggest that Central and SE Pamir, together with Karakoram and Qiangtang blocks separated from the Gondwana margin in the Early Permian, drifted northward, following the closure of the Paleotethys and other minor oceanic branches, and diachronously collided with Northern Pamir and Tian Shan. The Central and South Pamir are now separated by the Rushan-Pshart Suture Zone that extends E-W from the E-Pamir Fault ??? to the valley of the Panj River.

South Pamir is separated into two units (SE and SW Pamirs) by a crustal scale detachment system that brought in contact the Permian to Cenozoic sedimentary succession of the SE block with the gigantic basement domes of the SW block, made of Precambrian metamorphic rocks with an high-T overprint of Miocene age. In SE Pamir the occurrence of Cimmerian tectonics is proved by lowermost Jurassic deposits resting in unconformity on intensively folded and faulted Permian and Triassic units. On the base of available data the suggested collision age of SE Pamir with Central Pamir is roughly bracketed between Middle Triassic to Early Jurassic.

Along the contact between the SE and SW Pamir, a small (a few tens of km^2 wide) ophiolitic unit occurs: the Bashgumbaz ophiolites. They consist of a low-grade metamorphic association of serpentinized harzburgites and gabbros with minor bodies of quartzdiorite and plagiogranite including olistolithic blocks with Triassic faunas related to Central Pamir by previous authors. Geochemical data suggest a supra-subduction zone affinity for the gabbroic complex. Significant enrichment in LILE and LREE compared to HREE, coupled with negative anomalies of Nb, Ti, Zr and other HFSE is coherent with this interpretation. U-Th-Pb dating of zircons from a quartzdiorite provides a Carnian crystallization age. Deformation and metamorphism (up to greenschist facies) that affected the Bashgumbaz complex should therefore been placed in the Late Triassic.

We suggest that the Bashgumbaz ophiolites formed in a supra-subduction setting and were later underthrusted and then obducted onto the southern margin of the closing Rushan-Pshart ocean. The obduction of the Bashgumbaz ophiolites could be considered as a time-marker for the accretion of the South Pamir terrane to the Eurasian margin.

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Tectonometamorphic evolution, tectonic coupling and exhumation history of the Ötztal, Schneeberg and Texel unit (Eastern Alps, NE Italy)

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Keywords: Eastern Alps, Austroalpine, Cretaceous metamorphism.

The Austroalpine nappe stack to the west of the Tauern Window is made of three main tectonometamorphic units that are, from top to bottom: the Ötztal-Stubai complex, the Schneeberg and the Texel units. The Ötztal-Stubai complex consists of a polymetamorphic basement and Permian-Mesozoic sedimentary rocks that underwent metamorphism and deformation during the Alpine orogeny. E and NE of Vipiteno (Schneeberg, Telfer Weissen, Tribulaun) the non-conformity surface between basement and the metasedimentary succession has been mapped in details in the frame of the CARG project of the Provincia Autonoma di Bolzano-Alto Adige. As the non-conformity is still roughly preserved, structural investigations across such discontinuity are useful to reconstruct the Alpine deformation history. Mafic to intermediate dikes that cut across the basement regional foliation but do not intrude the post-Variscan cover are additional structural markers.

The Ötztal cover consists of a metaconglomerate (Basal Conglomerate Auct., Permian), containing quartz, gneiss and garnetite clasts, a thin level (1-20 meters thick) of quartz-carbonatic schists, calcitic-dolomitic marbles, graphitic calcschists and, at the top, dolomitic marbles. Even if the non-conformity between the basement and the overlying metaconglomerates is variably interested by shear zones, the occurrence in the metaconglomerate of clasts strictly deriving from the underlying basement suggests that displacement due to shearing is limited: garnetite clasts occur only in the Schneeberg area where garnetite levels, not found elsewhere, occur within Ötztal micaschists.

Alpine deformation resulted in a penetrative foliation in the sedimentary cover coupled with a stretching lineation due to a top-to-W (NW) shearing. Mafic-intermediate dikes are substantially undeformed, displaying only a faint foliation close to the contacts with host gneisses. The Ötztal basement did not have suffered penetrative recrystallization and deformation during the Alpine cycle: dikes cut across not only the regional foliation but also the last fold system that fold it. P-T estimates constrain metamorphic condition in metaconglomerates and dikes at 450-500°C and 0.8-1.0 GPa. Ar-Ar dating of micas aligned along the main foliation in conglomerates and recrystallized biotite in dikes provide ages of about 85 Ma. These data are very close to the age of the eclogitic metamorphism in the Texel unit and the HP amphibolite facies metamorphism in the Schneeberg complex. All together these data suggest that metamorphic peak conditions were experienced roughly contemporaneously by the three units when they were at different crustal levels. During exhumation, the HP Texel unit was first coupled with the Schneeberg unit (the two units show a common evolution since the amphibolite facies re-equilibration of the Texel eclogites) and then the Schneeberg-Texel was brought in contact with the Ötztal basement and cover at shallow crustal level.

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Strain partitioning during oblique convergence: the Aghdarband case-study, NE Iran

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Keywords: NE Iran, Kopeh Dagh, transpression, oblique convergence, Triassic, Cimmerian orogeny, structural

The Aghdarband Basin, consisting of a strongly deformed arc-related Triassic marine succession, is a key-area for the study of the Cimmerian events, as the Cimmerian deformational structures are sealed by the Middle Jurassic to Cenozoic poorly deformed units of Kopeh Dagh, NE Iran. Aghdarband is located to the north of the Palaeotethys suture zone, which records a Devonian to early Mesozoic convergence. The integrated stratigraphic and structural analyses of the Triassic successions of Aghdarband give new insights on the Cimmerian collision. Based on detailed fieldwork, we refined the previous stratigraphic framework and we performed meso- to megascopic structural analyses of the upper Palaeozoic to Triassic units of the area. Our data suggest that the Triassic sedimentation occurred in an extensional/transtensional basin characterized by important synsedimentary faulting activity. During the latest stages of the Cimmerian deformation, the Triassic successions, including the Upper Triassic Miankuhi Fm. were severely deformed into a N- to NNE-verging imbricate thrust fan, interacting with an ESE-WSW left-lateral wrench fault zone, the Northern Fault, producing positive flower structures with high angle reverse faults. The thrust stack, occurring to the south, extends for some tens of kilometres, involving Upper Permian conglomerates. It can be interpreted as a compressional retro-wedge formed in an arc/back-arc position with an opposite vergence with respect to the main collisional zone deriving from N-directed subduction of the Palaeotethys. One of the most peculiar characters of the area, given by the occurrence of megascopic plunging to vertical folds, is closely associated with the transpressional regime due to the activity of the left-lateral shear zone occurring in the northern part of the area. Curvilinear vertical fold axes result from hinges rotation during progressive deformation and to dragging occurring along the main strike-slip faults. Preliminary results from kinematic modelling of passive hinge rotation in triclinic transpression suggest that any hinge line formed at the onset of deformation will rotate during progressive deformation towards the extrusion direction of the pure shear component of transpression. This occurs with different combinations of the characteristic transpressional angles: transpression obliquity and extrusion obliquity. It appears that for any of these combinations, higher kinematic vorticity values produce larger rotations and thus will explain wider distributions of fold axes orientation. This peculiar setting results from nearly complete strain partitioning between mainly reverse and strike-slip faults and can be related to the reactivation of previous tectonic discontinuities affecting the Eurasian basement of the Kopeh Dagh region, resulting from oblique convergence during the final stages of the Cimmerian collision.

SESSION S7

Post-orogenic extension in circum-Mediterranean belts: geomorphic signature, fault systems architecture and tectono-sedimentary evolution of syn-tectonic basins

CONVENERS AND CHAIRPERSONS

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The Quaternary tectono-sedimentary evolution of the intermontane basins surrounding the Matese Mountains (Central-Southern Apennines)

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Keywords: Chrono-stratigraphy, Facies analyses, Palaeoenvironments, Extensional tectonic, Matese Mountains.

The Matese Mountains are located in the inner part of the Central-southern Apennines and surrounded by several morpho-structural depressions: to the west, the Venafro and Isernia basins, from north to east, the Carpino, Sessano, Boiano and Sepino basins, from south to south-west, the Calore River valley and the Alifana Plain.

These intermontane basins are filled with thick Quaternary successions and, therefore, are key areas for the understanding of the Quaternary tectonic evolution of the Apennines chain. Since some years, they are subject of an interdisciplinary study underway by our research group, based on geological-geomorphological surveys, the stratigraphic-structural and sedimentological characterization of outcrops and deep borehole successions and tephrological, paleomagnetic, pollen and chronological analyses (Amato et al., 2011; Aucelli et al., 2011; Amato et al., 2014).

The main obtained results highlight that the sedimentation started in the Lower Pleistocene and first occurred under dominating lacustrine and palustrine conditions. During the Middle Pleistocene (starting from 0.4 Ma BP), primarily fluvial-marshy environments and secondly lacustrine and palustrine ones characterized the basins. From 0.3 Ma BP onwards, sedimentation continued with fluvial-marshy deposits.

The environmental and sedimentary evolution was guided primarily by tectonics and secondly by climatic variations. The data collected highlight that the basins were affected by NW-SE tectonic extension between Lower Pleistocene and early part of Middle Pleistocene and after by NE-SW extension. Obtained geological and structural data show that the extension was guided by mainly NW-SE, NE-SW and E-O oriented high-angle faults, bordering or intersecting the basins. Some of these faults can be considered still active and are partially capable to generate earthquakes.

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Unraveling supradetachment basin evolution by detrital apatite fission track analysis: the Gediz Graben (Menderes Massif, Western Turkey)

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Keywords: Detrital thermochronology, Apatite fission track, Supradetachment basin, Menderes Massif, Aegean.

The Menderes Massif (Western Turkey) is a Tertiary metamorphic core complex exhumed in the upper Oligocene-Miocene, during sedimentation in a series of E-W trending basins. Several studies addressed the exhumation history of the massif, but the depositional history of these basins is still poorly defined. In this work, we focus our attention on the supradetachment basin of the Gediz Graben, which will be used as a case history to illustrate the benefits of a comprehensive approach to detrital fission track dating that combines analysis of modern river sediments, analysis of fossil sedimentary successions, and mineral fertility determinations. We use this approach to constrain the age of barren sedimentary successions inside the basin, to determine the modern erosion pattern in the study area, and to track the exhumation history of the footwall units. Our results allow us to propose a 4D reconstruction of the Gediz Graben evolution, which is eventually discussed within the framework of the Cenozoic evolution of the Menderes Massif and of the Eastern Mediterranean region more in general.

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LANF-driven Quaternary extension in the Calabria-Lucania Region (Southern Apennines, Italy)

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Keywords: Northern Calabria, Extensional Tectonics, East-dipping LANFs.

In the Calabria-Lucania Quaternary extensional belt (southern Apennines), a large amount of deformation was accommodated by LANFs.

New geological mapping, integrated by structural analysis and, locally, by seismic lines interpretation, allowed us to delineate two previously unknown, nearly N-S striking, LANFs dipping to East and outcropping over distance of nearly 90 km.

The northern structure, hereinafter referred to as *Lucania-Calabria Detachment Fault* (LCDF), dissects the eastern slope of the mountain ridge separating the Mercure Quaternary basin from the Tyrrhenian sea. It has been mapped for nearly 30 km along strike. Along the eastern slope of the Mt. Ciagola ridge, low-angle east-dipping normal fault planes (15°-30°), juxtaposing the Liguride unit on the Triassic dolostones of the Verbicaro unit, are well exposed. The most spectacular spectacular fault mirrors, with an associated offset exceeding 2 km, have been recognised in the Lao Valley. Regional-scale fieldwork highlights that the LCDF is the westernmost structure of a set of synthetic sub-parallel normal faults, that display dip-angles gradually increasing from west to east. A conservative estimate of the cumulative displacement, occurred on the LCDF and on its major synthetic splays, provides values of nearly 3500 m.

The southern structure, hereinafter referred to as *North Calabria Detachment Fault* (NCDF), was reconstructed for nearly 60 km along-strike, along the eastern side of the S. Donato metamorphic core and of the Catena Costiera. Moving from north to south, the NCDF bounds to the west the Castrovillari and Crati Quaternary basins and its surface expression corresponds to the S.Sosti-aracena and the San Fili-S. Marco Argentano normal faults, respectively.

Across the central part of the NCDF, a seismic reflection line, crossing eastward the whole Crati basin, was interpreted and depth converted. The section shows as the NCDF, that crops out along the eastern slope of the Catena Costiera, dips eastward at an average angle of 30°, reaching depths of at least 8-9 km. The geometry of the syn-tectonic deposits, their structural setting and the detailed review of their stratigraphy, suggest that the high-angle normal fault set, branching upward from the NCDF, is characterized by a progressive eastward-younging trend with the most recent splays bounding the western edge of the present Crati floodplain.

The time of activity of the two regional LANFs (LCDF and NCDF) are yet to be accurately constrained. Some scattered crop out of ancient slope debris dissected by the LCDF suggest an onset not older than Early Pleistocene times. Similar inferences can be formulated for the NCDF, based on the geometry of the syn-extension sedimentary prism.

Stratigraphic and morpho-structural data show that during the middle-Late Pleistocene, extensional deformations migrated eastward and concentrated on the outermost high-angle synthetic splays of both LANFs.

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Plio-Pleistocene structural inversion around the Catanzaro Trough (Calabria, South Italy): change from transcurrent to extensional kinematics?

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Keywords: faults inversion, strike slip, stress field.

The Catanzaro Trough basin (Calabria, South Italy), extending from the Tyrrhenian to the Ionian Sea, filled by up to 2000 m of Neogene- Quaternary sedimentary succession, represents a key zone to understand the evolution of entire Calabrian Arc.

This basin is characterized by multi-phases tectonics that have acted in the study area since the Upper Miocene. To gain knowledge about this area, we focused the study on the fieldwork survey, which allowed to acquire more than 700 fault planes, classified on the base of kinematics and fault direction, evenly distributed throughout the area. These data were used to obtain the stress fields that have controlled the evolution of the Catanzaro Trough. Indeed the collected data analysis supplies information about three main structural events: Upper Miocene-Zanclean, Piacezian-Lower Pleistocene, and Middle-Upper? Pleistocene phases, alternatively controlled by the activity of NW–SE and NE–SW oriented fault systems.

The selected major NW-SE oriented faults showing left lateral kinematics, together with secondary fault systems represented by E-W oblique and NE-SW transcurrent faults are the result of a paleo-stress with ca. E-W-trending maximum principal σ_1 axis (P-axis) and a horizontal NNW-SSE extensional σ_3 axis (T- axis), responsible for the Upper Miocene-Zanclean opening of a WNW–ESE fault bounded basin.

During Piacezian-Lower Pleistocene, a change of stress field seems to yield inversion of major left-lateral faults, suggesting a new stress regime, with a ca. N-S oriented maximum principal axis (σ_1), and a ca. NW-SE oriented minimum principal axis (σ_3), compatible with the right-lateral motion of the same fault system This structural stage, in turn, was replaced by extensional phase, with a (σ_3), ca. WNW-ESE oriented, controlled mainly by NE-SW and subordinately N-S oriented normal faults, which split obliquely the Catanzaro Trough, producing up-faulted and down-faulted blocks, arranged as graben-type systems (i.e. Lamezia Basin, Brutto et al., 2016).

These last two fault systems give also indication of recent (post Middle-Upper? Pleistocene) faults activity of an area historically considered with the highest probability of occurrence of major earthquakes throughout the whole Italy.

Brutto, F, Muto, F., Loreto, M. F., Tripodi V. & Critelli S. 2016. Transition from strike-slip to extensional tectonics in the Plio-Pleistocene Catanzaro Trough (Calabria, south Italy). Rendiconti Online Società Geologica Italiana, Vol. 38, 9-12.

Detailed field mapping and seismic analysis of potentially seismogenic faults at the Calabria-Lucania Boundary (southern Apennines)

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Keywords: Southern Italy, Quaternary and active extensional faults, earthquakes location, earthquake/fault.

We report on the results of our research activity, carried out in the context of the DPC-INGV S1 project 2014-2015, primarily devoted to elaborate the Map of Active Faults in the Calabria-Lucania Region.

In particular, we focus on a newly found Quaternary and active normal fault-system, which crops out in the Mercure-Pollino area, a highly seismogenic sector of the southern Apennines, Italy. From 2010 to 2014, this area was affected by long lasting seismic activity culminated in the October 2012, M_w 5.2 Mormanno earthquake and in the May 2012, M_w 4.3, Morano Calabro earthquake.

The seismicity pattern occurred in one of the areas with the highest seismogenic potential in Italy, that was struck in the past by strong earthquakes and with active structures capable of generating earthquakes up to magnitude 7. None of the previously known active structures was compatible with the position and the geometry of the seismogenic source suggested by the hypocentral location of the main shock, and by the overall geographical distribution of the seismicity.

The integration of new structural-geological data, integrated with the visual interpretation of stereoscopic aerial photographs and morpho-structural analyses executed in and near the epicentral area of the 2010-2014 Pollino seismic sequence, allowed us to map a number of previously undiscovered Quaternary extensional faults, to establish their geometry and kinematics, and to define the style of the extensional tectonics in the area. For some of defined faults, the cross-cutting relationships and the slip rates of the single active fault-segments were determined.

By comparing the reconstructed fault geometry with the hypocentral distribution and the time-space evolution of the Pollino 2010-2014 seismic activity, we identified the seismogenic sources in two, near-parallel WSW-dipping faults, i.e. the Rotonda – Campotenese fault and the Morano Calabro – Piano di Ruggio fault. These two structures are antithetic to a coeval east-dipping extensional detachment that crops out in the eastern slope of the Gada-Ciagola Mnts. and in the Lao river valley.

The reconstructed asymmetric extensional pattern, characterized by high-angle west-dipping faults antithetic to low-angle east-dipping ones, shows affinity with similar active and seismogenic fault-systems already described in other sectors of the Apennine extensional belt.

New insights into the onset and evolution of the central Apennine extensional intermontane basins from the tectonically active L'Aquila Basin (central Italy)

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Keywords: extensional intermontane basins, L'Aquila Basin, Central Italy.

The tectonically active L'Aquila Basin offers new insights into both the creation of the extensional intermontane basins of the central Apennines of Italy and their tectono-sedimentary evolution through time. Our results on large mammal remains, ostracods, molluscs, Mousterian tools, and ^{14}C dating allowed us to better define the onset and the stratigraphic evolution of the L'Aquila Basin. Interpretation of a seismic reflection profile and well log data moreover allow us to decipher the subsurface setting of this sedimentary basin and its tectono-sedimentary evolution. The occurrence of a wedge shaped seismic unit at the base of the basin sedimentary fill defines the first phase of basin filling during a late Piacenzian-Gelasian syn-rift stage. Activity along the main fault of the extensional fault system responsible for the onset and subsequent development of the western sector of the L'Aquila Basin (L'Aquila-Scoppito Sub-basin) migrated from southwest to northeast, reaching the presently active Mt. Pettino normal fault only in the late Pleistocene-Holocene. Our results showing an onset of the L'Aquila Basin that is synchronous with the onset of the Tiberino Basin call into question the notion that these extensional intermontane basins become younger from the Tyrrhenian towards the Adriatic side of the central Apennines. Our new insights into the onset of the central Apennine extensional intermontane basins together with their seismic activity allow us to consider the central Apennine post-orogenic extensional domain as an archive of ca. 3 My of continued crustal extension. Our findings can help to refine the long-term extensional rate of the central Apennines, as well as to develop more reliable seismotectonic models for one of the most seismically active sectors of the central Mediterranean area.

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Inherited fault system control on seismogenic activity: the North Matese case (Molise, Italy)

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Keywords: Late-Quaternary active faults, segmentation, slip-rates, seismogenic sources, Matese Mts, central

During Quaternary times, the Apennines of Italy experienced NE-SW extension which conditioned the evolution of intra-montane basins mainly bounded by SW-dipping seismogenic normal faults. The Matese Mts (Molise region) bring evidence of this tectonics starting from the Middle Pleistocene (Amato et al., 2014) and with the onset, along its northern slope, of the Bojano basin. The depression exhibits a NW-SE general trend but a highly segmented array of N- to NE-dipping normal faults clearly controlled its development.

The area is well known for its high seismic hazard, testified by relevant historical seismicity (Rovida et al., 2011) and by geodetic deformation velocities (1-3 mm/yr) considerably high (Giuliani et al., 2009; Ferranti et al., 2014). Conversely, the instrumental seismicity in the last decades has been only characterised by low energy swarms.

Taking into account of this framework, we investigate the geometry and kinematics of the North Matese Fault System mainly focusing on two differently oriented fault sub-systems, the NW-SE Patalecchia-Colle di Mezzo and the E-W Bojano-Guardiaregia. The study was mainly based on field mapping, structural analysis and log interpretation. New evidence of Late Quaternary faulting were pointed out and post LGM (15k±3 kyrs) estimates of the throw/slip rates were also provided. Furthermore, the fault segmentation pattern and related strain partitioning were constrained and the role played by inherited structures in controlling the recent extensional tectonics was highlighted. The coherence of the fault system with the Quaternary stress field, in central Italy, was verified (Ferrarini et al., 2015).

To conclude, all the geological information was integrated with available seismological data, in order to connect the shallow geometry of the seismogenic sources with their likely down-dip extent. A possible association with major historical earthquakes was outlined.

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3D Quaternary extensional fault model of Italy: from surface to earthquake depths

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Keywords: Quaternary extension, 3D fault model building, regional extensional detachment, Italy.

Based on integrated structural, seismological and geophysical data, we propose an unified 3D regional view of the Intermountain Extensional Belt (IEB) of Italy, suitable for seismic hazard purposes.

The IEB is an active and seismogenic normal and normal-oblique fault system that extends for about 1500 km across the Apennine-Peloritani mountain chain, rotating in strike from NW-SE in the north, to N-S in Calabria and E-W in Sicily. The IEB is characterized by an outcropping system of Quaternary moderate-to-steeply dipping (60°±15°) normal and normal-oblique faults that dip toward the Tyrrhenian hinterland and are antithetic to a coeval, and/or slightly older in the initiation age, system of foreland-dipping moderate-to-low dipping (30°±15°) normal and normal-oblique faults. We refer to the two systems as HANFs (high-angle normal faults) and LANFs (low-angle normal faults). The HANFs are long known in the literature. The LANFs, which do not have strong morphological expression, have been recognized more recently in northern and southern Italy (Etrurian Fault System and Campania-Lucania Extensional Fault System), as well as in central Italy along the Latium-Abruzzo border. They are also hypothesized offshore northern Sicily.

Crustal transects across the IEB show that the outcropping HANFs and LANFs sole to a common detachment, here referred to as Italian Extensional Detachment (IED). The IED dips at low-angle, with a ramp-flat-ramp-geometry, toward the Adriatic-Pelagian foreland, reaching depths up to 15-16 km. This geometry is constrained by the integration of structural geological data with relocated cluster of hypocenters and/or relocated background seismicity and with focal mechanisms. Whenever available, seismic reflection and well data were used.

In order to obtain a schematic three-dimensional representation of the IED and its hanging-wall structures, we interpolated the available surface and depth data using the Move suite of the Midland Valley software. Most of the outcropping faults are individual segments active in late Quaternary times, whose association with moderate to larger historical and instrumental earthquakes ($M_w \geq 5.5$) has been established in the literature. The model shows as outcropping individual segments may be interconnected at depth, increasing the probability of multi-fault ruptures. The model also highlights the regional relevance of the IED, that plays the role of intracontinental Seismogenic Boundary Fault, bounding a wedge-shaped intra-Apennine actively extending crust volume.

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The alluvial fan system of the northern slope of the Camposauro Mountain: the role of tectonics and climatic fluctuations since the late Middle Pleistocene

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Keywords: alluvial fan, Calore River, tephrostratigraphy, Quaternary tectonic, Southern Italy.

The northern slope of the Camposauro Mountain is characterized by an alluvial fan system that started growing since the Middle Pleistocene. This depositional system passes upslope to well cemented Lower Pleistocene breccias of the Laiano Synthem and passes downslope to the alluvial deposits of the lower reach of the Calore River Valley. The latter is E-W oriented, structurally controlled, with an asymmetric cross profile characterized by a wide and gentle right flank with, at least, five orders of terraced alluvial deposits. Many studies (Di Bucci et al., 2006; Magliulo et al., 2007 and references therein) have constrained the alluvial terraces to the Middle Pleistocene-Holocene time span, pointing out the role of high angle tectonic activity in the evolution of this flank. On the contrary, the left flank of the Calore River valley, where the Camposauro piedmont is located, has been less investigated and the here located alluvial fan system that has been generically ascribed to the Middle Pleistocene (Bonea subsynthem). We present the results of a multidisciplinary study based on field survey, tephro-stratigraphic and geomorphologic analysis of the Camposauro alluvial system. In detail, the northern flank of the massif is characterized by a steep slope (70°-35°), partially controlled by a ca. E-W oriented fault system, and a wide, less-inclined piedmont aggradation zone. The new collected data show that the Quaternary morpho-stratigraphic evolution of the fan system, as well as that of the fluvial terraces on the opposite valley side, has been conditioned by extensional tectonics that acted along ca. E-W trending high angle faults.

Three generations of alluvial fans have been recognized and chronologically constrained. The first generation is terraced and contains, in its upper part, interbedded tephra layers ascribed to the end of the Middle Pleistocene and the first part of Upper Pleistocene. The second and third generations of alluvial fans can be constrained respectively to the Late Pleistocene and the Holocene, thanks to the presence of interbedded tephra layers referred to the Campanian Ignimbrite (39 Ky BP) and the Neapolitan Yellow Tuff (15 Ky BP).

Structural and morpho-structural data suggest that tectonic activity influenced the growth of these alluvial fans at least up to the second generation. This assumption is also supported by Di Bucci et al. (2006) that have identified faulted slope deposits containing a tephra layer dated to 45ka BP.

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A multidisciplinary approach to understand the interaction between faults and fluid circulations: the continental Triponzo basin case history (northern Apennines, Italy)

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Keywords: Triponzo, travertine, CO2, extensional tectonics.

A multidisciplinary approach was carried out in the Quaternary continental Triponzo basin (northern Apennines, Umbria region) with the aim of developing a comprehensive understanding of the relationship between tectonic and fluid circulation processes that have promoted deposition of widespread continental carbonates. The area is located at the intersection of the Nera and Corno rivers, where some of the Meso-Cenozoic carbonate-rich formations of the Umbria-Marche sequence are in tectonic contact along two N-S and NW-SE oriented tectonic systems. Active thermal springs are present in the sector of tectonic intersection. The area is also characterized by moderate seismicity related to extensional tectonics.

We performed an integrated study including stratigraphic, structural and geochemical analyses. A detailed geological survey was performed in order to define the areal and vertical distribution of the continental deposits. The stratigraphic data allowed to identify three main depositional stages occurring during the Pleistocene-Holocene, testifying a complex interaction between clastic-dominated (lacustrine and fluvial deposits) and carbonate-dominated (tufa) depositional environments.

The structural analysis of faults and fractures was carried out on the bedrock because the continental deposits are apparently undeformed. The results shows the occurrence of two main fault systems. The first one is characterized by N-S trending fault system with offsets of the order of some hundreds meters. The second system consists of mainly N110-N120 trending right lateral transtensional faults with small offsets. The reconstruction of the strain field of the structural data is consistent with nearly pure extension with maximum extensional strain oriented NE-SW according to the present Apennines extensional regime.

The geochemical survey allowed to create a map of the CO_2 fluxes anomalies. The map shows that the main anomalies are located on the western sector of the Nera valley, associated to the WNW-ESE trending transtensional fault zones. The chemical compositions of both thermal and cold waters suggest a mixing process among shallow aquifer and sulphate rich waters circulating in a deep aquifer, including the Evaporitic Triassic Formation. Geothermometry and geobarometry calculations, based on HCO_3-SO_4-F contents, indicate a temperature about 75°C and a PCO_2 from 0.1 to 1 for the deep system feeding Triponzo springs.

These data confirm a deep hydrothermal circuit with a water–rock interaction. Furthermore, a local NE-SW oriented extensional regime, enhancing the migration of thermal fluids and CO_2 degassing, is inferred by the results of the structural analysis carried out on the faults and fractures. Our results suggest that both the thermal and the fault systems are still interacting and active in the study area.

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Geomorphological signature of Pliocene-Quaternary tectonics in the axial zone of the southern Apennines, Italy

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Keywords: Regional morphotectonics, long-term landscape evolution, uplift and erosion rates, southern Apennines.

The multidisciplinary approach to the study of the surface processes and landscape evolution of a tectonically active mountain chain represents an obliged way to get reliable information about the mechanisms of interplay and feedback between tectonics and climate. One of the main tool to obtain information about the dynamic state of an orogenic chain consists of the estimations and comparison of uplift and erosion rates, calculated for quite different time intervals and used to understand both long- and short-term surface processes. Here, we review the results of more than twenty years of scientific investigation performed in the Campania-Lucania and northern Calabria segments of the southern Apennines, particularly in the axial zone of the chain – largely affected by post-orogenic extensional tectonics – where several intermontane basins filled by Pliocene and Quaternary clastic deposits are present. Further, we compare them to other similar results obtained from different segments of the chain. The regional-scale morpho-structural analysis, the recognition and dating of features related to ancient base levels and used as reference levels for the rates calculations, the quantitative evaluation of the erosional processes, the estimation of tectonic loadings suffered by the sedimentary rocks that form the backbone of the southern Apennines and the consequent estimate of the exhumation rate of the non-metamorphic "core complex" of the chain, the recognition and recording in a wide area of palaeoclimate proxies, such as palaeosols, weathering horizons, planation surfaces, and palaeolandslides, allowed us to obtain a detailed and synoptic picture of the landscape evolution of the chain during the last 3 Ma. Uplift and erosion rates have been calculated for a large sector of southern Italy, using both geomorphological observations (elevation values, ages and arrangement of depositional and erosional land surfaces and other morpho-tectonic markers) and stratigraphical and structural data (sea-level related facies, base levels, fault kinematics, and fault offset estimations). The values of the Quaternary uplift rates of the southern Apennines vary from 0.2 mm/yr to about 1.2-1.3 mm/yr. The erosion rates from key-areas of the southern Apennines, obtained from both quantitative geomorphic analysis and missing volumes calculations, has been estimated at 0.2 mm/yr for the Middle Pleistocene to Present time span. Since Late Pleistocene erosion and uplift rates match well, the axial-zone landscape could have reached a flux steady state during that time, although it appears more probable that the entire study area may represent a good example of transient landscape. Tectonic denudation phenomena – leading to the exhumation of the Mesozoic core of the chain – followed by an impressive regional planation started in the Late Pliocene have to be taken into account for a coherent explanation of the morphological evolution of southern Italy.

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Strike slip and extensional tectonics in the Neogene-Quaternary between the Serre and Aspromonte Massif, Calabria (southern Italy)

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Keywords: Calabrian Arc, Extensional tectonics, Strike slip tectonics.

The role of strike slip and extensional faults in the Neogene-Quaternary evolution of Back-arc and Forearc, between the Serre and Aspromonte Massifs, located in the southern Calabrian Arc, is documented in the exposed sedimentary successions, part of a larger Neogene forearc basin developed in the Ionian Sea and the back- arc basin in the Tyrrhenian side. Since Miocene, the area experienced different tectonic phases responsible of the variation of basinal architectures and forming both longitudinal and transversal fault systems. The structuration of these different basins is the answer of the southeastward migration of the Calabrian Arc, which led to the subduction of the Ionian lithosphere and the spreading of the Tyrrhenian back-arc Basin.

In this area, NW–SE and NE–SW fault systems are dominant. The first exhibiting strike–slip, oblique and normal kinematics. The strike–slip and oblique slip accommodated stress generated in the accretionary prism in response to subduction of Ionian lithosphere and progradation of the accretionary front of the Calabrian forearc (Ortolano et al., 2013; Tripodi et al., 2013), these structures were active during infilling of the Neogene basins, and represent a complex transfer zone (Tripodi et al., 2013). The NE–SW system shows two dominant types of tectonic kinematics: (1) a compressive, with NW–SE-oriented shortening, responsible for inversion tectonics documented by east-verging folds, thrusts, and back-thrusts, well documented in the basinal succession and in the offshore wells; (2) an extensional tectonics that has produced a segmentation of the study area.

Since Middle Pleistocene - Upper Pleistocene the tectonic extension represents the deformation pattern driving the Calabrian Arc uplift. The main morfostructural expression is the NNW-SSE structures like the Nicotera Gioiosa - Palmi–Locri and Bovalino Bagnara faults in the ionian side and the NNE-SSW oriented Cittanova fault, in the Tyrrhenian back-arc Basin. The last system plays a relevant role as part of recent seismo-tectonic processes controlling the Late Quaternary geodynamic evolution of the area and influencing the configuration of marine and continental terraces outcropping along the Ionian and Tyrrhenian sides of the southern Calabrian Arc.

Considering these features, the improvement of geological and structural knowledge of the study area provided new insights about the geodynamic evolution of the whole Calabria Arc and new elements about Quaternary faults activity within this region.

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SESSION S8

Tectonics and igneous activity

CONVENERS AND CHAIRPERSONS

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Fault-controlled volcanic vents between the Volsci Range and the magma-rich Tyrrhenian passive margin (Italy)

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Keywords: Volsci Range, Tyrrhenian passive margin, aquifer, phreatomagmatic eruptions, slab tear.

Newly discovered volcanic vents were recently mapped along major fault zones both inland and offshore the Tyrrhenian magma-rich passive margin, which is the result of Plio-Pleistocene crustal thinning. The margin is now stretched over 100 km between the Volsci Range (VR) and the Pontian escarpment, being defined by moderate shallow seismicity (Mw≤4.6), relative high geothermal gradient and ongoing hydrothermal activity. Although major central volcanoes (e.g., Colli Albani) occurring at major fault intersections are well studied, timing and role of smaller volcanic fields were so far not considered. Both field survey in the VR and offshore high-resolution geophysical data, allow us to: 1) better define the anatomy of the poorly known VR volcanic field; 2) furnish new insights on the regional Quaternary dynamics; 3) explain modes and reason of magma emplacement. Indeed, the VR is composed of about 40 punctual and linear monogenic and mostly phreatomagmatic vents occurring at the edges of the Apennine carbonate fold-and-thrust belt and within the VR backbone over an area inhabited by some 0.4 million people. Volcanites are characterized by zeolitized to incoherent tuffs and surge deposits locally followed by lavas and slope deposits. Most explosive units are rich in carbonate lithics with different degrees of rounding and decarbonation that frequently belong to Albian-Cenomanian aquifers. By comparing cross-section with lithic analyses we demonstrate that fragmentation, transport, progressive disintegration and decarbonation occur at multiple depths, depending on the fold-and-thrust belt setting. Thus, along the same vent zone, juvenile lithic composition proves repeated interactions between injected magma and aquifers, testifying for fissural activity with implications for local seismic and volcanic assessment. Pyroclastic deposits occur as well in the Pontina and Fondi coastal plains at shallow depth suggesting recent (<10 kyr) and possibly local eruptions. Offshore, 25 km north of Ventotene, a middle Pleistocene 200 m-high truncated volcano was found partially covered by middle to recent deposits. It is delimited by well defined WNW-striking fault-controlled escarpment dissected by NE-striking faults. As on the Ponza-Zannone high, volcanic complex occur on a horst intersecting the two main regional trends, possibly associated with younger SE-stretching. Quaternary stretching rotation occurs as a response to Tyrrhenian backarc opening and contemporaneous inarching of the Apennine front. In this frame, frontal to lateral slab tearing and retreat is tracked by E-rejuvenated volcanic activity along the Palmarola-Vesuvius lineament. In conclusion, we argue about the role NE-dipping crustal detachment(s) may have played into upper crust structuration, driving and occasionally hampering magma-emplacement.

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A shoshonitic multi-pulse intrusion in the Southern Alps domain (NE Italy): the Predazzo Intrusive Complex (PIC)

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Keywords: Predazzo volcano-plutonic complex, PIC, Triassic shoshonitic magmatism, volume estimates, Predazzo.

This work deals with the petrographic and geochemical study of the Triassic Predazzo Intrusive Complex (PIC).

This plutonic 4.5 km^3 body, surrounded by a 6 km^3 volume of basaltic to latitic associated volcanics, outcrops in the Dolomites (Southern Alps). It is composed by gabbroic to syenitic and syenogranitic rocks, as well as by a minor presence of cumulate clinopyroxenites. PIC is made up of three main magmatic units, named Shoshonitic Silica Saturated (SS, 67% of the total volume), Shoshonitic Silica Undersaturated (SU, 8%), and Granitic (GU, 25%), marked by a clear potassic affinity.

Distinctive geochemical features of the PIC rocks are the high K_2O content, marked Nb and Ti and progressive Eu negative anomalies and a strong Pb enrichment. Magma chamber fractionation processes in a partially closed system is calculated for both SS and SU suites, using mineral and whole rock (major and trace elements) compositions, in order to reconstruct the multi-stage PIC evolution and the link between the calculated subtracted solid assemblages and the real cumulate rocks sampled in the PIC area.

Accordingly, whole rock isotopic $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ signatures allow discriminating two main differentiation series: SS (0.70398-0.70491 and 0.51216-0.51223 respectively) and SU (0.70539-0.70653 and 0.51224-0.51228). Noticeable initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of SS samples, corrected at an age of 230 My, result comparable to the similar SS lithotypes constituting the Mt. Monzoni intrusive complex (Bonadiman et al., 1994). The study of the field relationships between SS, SU, GU and the dike swarm enables the reconstruction of PIC temporal evolution: the first magma chamber pulse is represented by the SS batch, followed by the GU and by the SU intrusion.

Finally, the existence of a caldera collapse (Castellarin et al., 1982; Doglioni, 1984) deduced by the ring-like shape of Predazzo volcano-plutonic complex seems unlikely due to: (i) the presence, both in eastern and western PIC edges, of a magmatic transitional contact between the SS rocks and the volcanics; (ii) the absence of large caldera-fill deposits.

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Architecture of the NYT caldera and inner resurgent dome (Pozzuoli Bay, Campi Flegrei): new insights from seismic reflection and DInSAR data

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Keywords: Collapse caldera, Campi Flegrei, ground deformation, inner-caldera resurgence.

The Campi Flegrei and its offshore prolongation (Pozzuoli Bay) are a volcanic area dominated by a collapse caldera associated with the Neapolitan Yellow Tuff (NYT) eruption, occurred at ~15 ka BP, and by an intra-caldera resurgent dome. We present new insights into: a) the geometry and kinematics of faults formed inside the caldera, b) the architecture of the resurgent dome, and c) the relationship between the structural elements of the resurgent dome and ground deformations. This work is based on the integration of high- and ultra-high resolution seismic data, swath bathymetry data and ground deformation maps. The main results highlight that the NYT caldera, offshore, is characterized by an ellipsoidal shape, elongated towards the ESE direction, with axes of ~8 km and ~7 km. It is bounded by a ~6 km long and 1–2 km wide ring fault zone (RFZ) mainly consisting of an inward-dipping normal fault system and antithetic, outward-dipping, faults. The sedimentary fill of the caldera is up to 60 m thick, and can be divided into six units, characterized by different seismic facies, composition and depositional process.The inner-caldera resurgent dome, ~ 5 km in diameter, is limited by inner boundary of RFZ and consists in a broad antiformal structure with brittle deformation localized in an apical graben. The base of the resurgence corresponds to the thalweg of the Epitaffio valley in the western sector of the Pozzuoli Bay and the Bagnoli valley in the eastern one. The maximum cumulative uplift of the resurgent dome is ~180 m while its average uplift rate is ~ 9–12 mm/year, between 15.0–6.6 ka BP. A subsidence of ~10 m is suggested by the drowning of the infralittoral prograding wedge below the present-day storm wave base for the last 2 ka.The deformation velocity pattern of the Campi Flegrei displays a radial symmetry centered on the Pozzuoli harbor. It is possible to distinguish three almost-concentric sectors namely S1, S2, S3 with decreasing velocity from S1 (13-32 mm/year) to S3 (0.3-7.7 mm/year). The highest value (26-32 mm/year) is recorded at the Pozzuoli harbor. Sector S1 is bounded by a NE–SW-trending fault to the west and NW–SE faults to the east. The data suggests that this sector coincides with the resurgent dome of NYT caldera. The base of the latter corresponds to the faults bordering sector S1, and it can be correlated with the base of the resurgence recognized offshore. Sector S2 represents a narrow strip located between the base of the resurgence and the onland prolongation of the inner boundary of the RFZ.The results of our research provide new insights into the stratigraphic architecture and the shallow structure of the NYT collapse-caldera in the Pozzuoli Bay. Furthermore, they represent a base to reconstruct the entire onshore-offshore geometry of the inner-caldera resurgence and infer new constraints on the dynamics of the fluid flow system and magma source at depth.

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Reconstruction of the eruptive dynamic of last Vesuvius eruption in March 1944

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Keywords: vesuvius, explosive eruption, distal ash.

Mount Vesuvius last erupted in March 1944. The eruption began with a modest effusive activity (18–21 March, phase I) and then moved on to a lava-fountain phase (21–22 March, phase II) that quickly culminated in a 24-h paroxysmal phase (22–23 March, phase III), during which the eruptive column reached its maximum altitude and ash carried by the wind was deposited at distances of up to 500 km from the volcano. Subsequently (phase IV), the ash cloud reached altitudes not exceeding 2 km above the crater and the explosions became discontinuous, alternating with frequent tremors. From April 7th the vent remained permanently closed. Since then, the current period of quiescence may be said to have begun. In our study we present a detailed geochemical study of the volcanic products emitted throughout the stages of the eruption, including an extreme distal ash sample, collected at the time of the eruption in Albania (Devoli) by the geologist Antonio Lazzari. The results indicate that magmatic differentiation took place in two crystallization stages under different temperature and pressure. Moreover, through the use of a numerical model of volcanic ash dispersion in the atmosphere as well as the collection of new witness accounts, we inferred the maximum height reached by the eruptive column (8–10 km above the crater) as well as its impact on the environment and people, suggesting that the damage in the area and even the number of the victims could be higher than accepted until now (Cubellis & Marturano, 2010; Cubellis et al., 2013, 2016; Pappalardo et al., 2014).

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Petrogenetic Features of the Granitic Pebbles within the Late Ordovician Glacial Diamictites in Tauride-Anatolide Platform of Turkey: Implication of the island arc/A-type magmatic rocks of the Sinai Peninsula

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Keywords: Late Ordovician, glacial deposits, Gondwana.

Late Ordovician (Hirnantian) glacial deposits cropped out in the northern margin of Gondwana (Africa and Arabia) and the southern margin of the European continent are one of the most extensive glacial deposits despite the duration of the glacial episode shorter than 1 million years (Ghienne, 2003). The glacial successions in the central and eastern Taurides are mainly composed of diamictites, conglomeratic sandstones, pebble-bearing sandstones, sandy diamictites, rounded-sub-rounded granitic pebbles (dropstone), rounded-sub-rounded lonestones, fine-grained sandstones, and sandy/muddy diamictites. The rounded/sub-rounded granitic/meta-granitic pebbles (dropstone) within the matrix of the diamictites are dated as 576.5±3.3 Ma (monzogranite-DPK44), 576.7±5.7 Ma (protomylonite-DPK27), 598.4±7.5 Ma (meta-granite-DPK72), 717.5±8.0 Ma (quartz monzonite-DPK30), 789.5±3.7 Ma (meta-granite- DPK17A) and 964.6±4.6 Ma (meta-granite-DPK46), respectively (Gürsu et al., 2016). All granitic pebbles are sub-alkaline and display tholeiitic affinity. The samples DPK 30 and DPK 46 have the lowest Th and Nb contents than all other granitic pebbles. The sample DPK 72 has slightly higher Th and moderate Nb contents. Low Th and moderate Nb contents of all analyzed granitic pebbles are just observed in DPK 27 and DPK 17A. But DPK 44 has the highest Nb and moderate Th contents when correlated with the other pebbles. All granitic pebbles have moderate to low Y values (< 40.00 ppm) and low to moderate Zr contents (112.1 to 225.8 ppm). DPK 46, DPK 30, DPK 27 and DPK 44 have moderate Nb/Th (1.50, 2.10, 1.48 and 1.63) and low Zr/Ti ratios (0.025, 0.037, 0.040 and 0.047) but DPK 17A and DPK 72 display moderate to high Zr/Ti ratios (0.118 and 0.130) with moderate to low Nb/Th (2.11 and 0.66) contents. The individual granitic pebbles have low to moderate La/Yb ratios (1.07 -DPK 27; 3.96-DPK 44, 4.82-DPK 30, 6.55-DPK 17A; 9.75-DPK 46; 15.14-DPK 72). Multi-element diagrams show that samples DPK72, DPK17A and DPK44 are more enriched in LREE than MREE and HREE. But sample DPK72 is more depleted for HREE than DPK17A and DPK44 and also displays negative anomalies for Nb and Ti. In chondrite and N-MORB normalized multi-elemental diagrams, samples DPK27, DPK30 and DPK46 show negative anomalies in Nb, La, Ce, Nd with enrichment in Th, Zr, Hf and are more depleted in REE than the other samples, but the HREE of DPK27 are higher than sample DPK30 and DPK46. The tectonic discrimination diagrams show that DPK17A, DPK30 and DPK 46 might have been derived from arc-type sources, whereas A-type tectonic environment (A_2-type alkali granitic sources) imply for the genesis of the samples DPK27, DPK44 and DPK72. The positive $_{\varepsilon}$Nd (+0.8 to +3.7) for the samples DPK30 and DPK17A imply that their protoliths might have been derived from mantle-derived sources. However, negative $_{\varepsilon}$Nd (-2.8 to -5.2) for the samples DPK44 and DPK72 show that their protoliths might have been derived from mantle bearing sources with assimilation of the crustal materials. Because of the alteration/fluid-ingress processes, the Rb-Sr and Sm-Nd parent-daughter ratios of the samples DPK46 (meta-granite) and DPK27 (protomylonite) were not used in determining their source characteristics. Based on their trace and REE patterns, they might have been derived from mantle-derived sources as MORB but high HREE/LREE ratio for the sample DPK27 indicates that garnet-bearing sources can be assumed for its magma genesis. The T_{DM} modal ages of the individual granites vary from 1.12 to 1.98 Ga that are older than their U-Pb crystallization ages and may indicate contamination of the older materials with mantle sources. However, the dated xenocryst ages show that individual granitic pebbles have limited older materials within the mantle sources that are compatible with their mantle derived arc-type and A-type source characteristics. The geochemical signatures and dated angular/sub-angular granitic pebbles in the central and eastern Taurides are interpreted to have been derived from equivalent Late Neoproterozoic granitoids/meta-granitic rocks in the Sinai Peninsula and cropped out in southern Egypt.

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The geodatabase of the geological map of Etna volcano. A GIS application for the dissemination and updating of the volcanological data

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Keywords: Etna, WebGIS, Geoddabase, update.

Starting from the GIS geodatabase used to create the geological map of Etna volcano at 1:50.000 scale (Branca et al., 2011, 2015) we have achieved a WebGIS geodatabase with the aim of disseminating and updating the geological and volcanological knowledge of one of the most active volcanoes in the world.

The WebGIS geodatabase is composed by 5459 polygons, each one describe by 19 string attributes and 2 geometrical ones (perimeter and area). We have added all the geological information derived from the original 1:10.000 field survey maps that not reported in the map at 1:50.000 scale. Furthermore, the last eruption reported in the printed map was that in May 2007.

The attribute table of the polygon layer contains the description of the corresponding lithostratigraphic units of the geological map. Concerning the volcanic products of the last 60 ka, mapped as flow-rank, we have reported for each lava flow several data such as the lithology, the distribution and morphology, the location of the ventfissure and other additional information (i.e. the original sources for the historical eruptions is indicated). Moreover, in the age field of the attribute table we have reported the data of the numerous radiometric age of the volcanic succession, the techniques and the related references.

The web-geodatabase of Etna volcano is available online (http://geodb.ct.ingv.it/geoportale/) since November 2015.

More information related to point and polyline layers is being in development in the geodatabase. In particular, we are inserting the samples location of rock analyzed, to chronological constrained the geological map, with the $^{40}Ar^{39}Ar$, $^{226}Rh^{230}Th$ and archeomagnetic techniques (De Beni et al., 2011; Tanguy et al., 2012). Moreover, we will insert other previous C^{14} age determinations and the location of the stratigraphic and tephrostratigraphic sections. To update the information about volcanic activity of Etna we have inserted all the volcanic products emplaced after the 2007 with until today.

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Monitoring of the stress field of volcanic areas

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Keywords: stress field, volcano-tectonic, focal mechanism.

Stress changes associated with the dynamics of magma chambers and hydrothermal systems are often linked to the occurrence of volcano-tectonic earthquakes in the surrounding areas. Since seismicity is a common feature of both quiescent and active volcanoes, their study allows to know the temporal and spatial pattern of the stress field. Recently the inversion of focal mechanisms, derived from seismological datasets, has shown to be a very useful and reliable tool to infer the stress field of active volcanic areas. Starting from fault kinematics and/or focal mechanisms many different inversion procedures can be applied. Analytical methods are based on the systematic comparison of the actual slip vector to respect the theoretical maximum shear stress acting on the same surface in response to the active stress field, for each slipped faults. Graphical methods allow the probabilistic determination of the range of possible attitudes for principal stress axes. Recently Massa and D'Auria (2015) proposed a new probabilistic formulation of the Right Trihedra Method allowing a quantitative estimation of the principal stress axes attitude as well as an estimation of the confidence regions and the corresponding Bishop ratio. The BRTM (Bayesian Right Trihedra Method) uses a Bayesian approach for the determination of the stress field from focal mechanism datasets, managing both homogeneous and heterogenous datasets. We present results from the inversions performed at Vesuvius (with a dataset of 197 FPSs), Campi Flegrei (with a dataset of 217 FPSs) and Long Valley (with a dataset of 38000 FPSs), using the BRTM. The results show that the stress field of these volcanoes derives from the interaction of a regional background field with local volcanic structures and from the volcano dynamics. This suggests that our approach can be applied to any volcanic context and can be used as a near real-time monitoring tool as well.

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Neogene volcanism around the Karlýova triple junction (Eastern Turkey)

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Keywords: Eastern Anatolia, Triple Junction, Neogene Volcanism, Petrology, Isotope Geochemistry.

The tectonic evolution of Eastern Anatolia is controlled by the north-eastward directed convergence of the African and Arabian plates towards Eurasia. Starting from the Middle-Late Miocene, the tectonic stress is mainly transferred along the East Anatolian and the North Anatolian Transform Faults Zones, intersecting in the Karlýova Triple Junction. The development of these fault systems determined the birth of Anatolia as independent microplate, the uplift of the eastern Anatolian Plateau, and a widespread volcanic activity, lasting from Middle Miocene to Pleistocene. Here, two different magmatic trends can be identified:

1) West to the triple junction, in Elazýð, Karakoçan and Pertek regions, the volcanic rocks define a clear chemical variation with age. The earliest products (16.2-15.7 Ma) show calcalkaline characters, with low TiO_2 (0.41-1.67), high La/Nb (2.3-3.5), strongly radiogenic $^{87}Sr/^{86}Sr$ (0.7052-0.7068), low $^{143}Nd/^{144}Nd$ (0.51246-0.51262) and high $^{207}Pb/^{204}Pb$ (15.70-15.71), including positive Pb and K anomalies as well as LILE and Sr enrichment in primitive mantle-normalized diagrams. Younger products (11.0 Ma) are transitional, with higher TiO_2 content (1.42-1.75) lower La/Nb ratios (1.3-2.3), lower $^{87}Sr/^{86}Sr$ (0.7040-0.7052) and $^{207}Pb/^{204}Pb$ (15.68-15.70) and higher $^{143}Nd/^{144}Nd$ (0.51270-0.51280). The evolutionary trend ends with the emplacement of youngest (4.1-1.7 Ma) sodic alkaline rocks, showing typical intraplate-like magmatic composition with highest TiO_2 (1.71-3.10), lowest La/Nb ratios (0.7-1.9), lowest Sr ($^{87}Sr/^{86}Sr$ = 0.7042-0.7048), highest Nd ($^{143}Nd/^{144}Nd$ 0.51270-0.51290) and lowest $^{207}Pb/^{204}Pb$ isotopic ratios (15.64-15.70).

2) East of the triple junction, in the Varto region, in a small area to the east of triple junction, the volcanic activity shows a more restricted time interval (3.6-0.5 Ma) without a clear evolutionary trend. Here it is observed a continuous variation, from calcalkaline rocks to Na-alkaline lavas, from basanites to rhyolites (e.g. SiO_2 from 44.3 to 70.1, TiO_2 = 0.3-2.7, La/Nb = 1.24-3.48), without any correlation with the age of the emplacement. It is noteworthy that $^{87}Sr/^{86}Sr$ ratios range from 0.7042 to 0.7055, differently from $^{143}Nd/^{144}Nd$, characterized by a much narrower variation (0.51269-0.51280).

This scenario implies the involvement of both a subduction-modified and a OIB-HiMu mantle sources, activated in different times west of the Eurasia-Arabia-Anatolia triple junction, and at the same time to the east of the triple junction.

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Water gain and loss and the advent of plate tectonics during the formation of the Earth

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Keywords: plate tectonics, formation of the Earth.

The formation of the Earth is now understood as a rapid transition from dust and gas to planetesimals, followed by a more protracted period of gravitationally-driven growth through planetary embryos the size of Mars, and finally to a completed planet. In tracing water through this process we find increasing evidence that while each heating stage involves the loss of water, none are sufficient to dry the planetary material.

Internal heat of planetesimals by short-lived radioisotopes likely lead to some water loss, but impacts into planetesimals were insufficiently energetic to produce further drying. In contrast, the giant impacts of late accretion created magma lakes and oceans, which degassed during solidification to produce a heavy atmosphere.

Water is thought to be critical for the development of plate tectonics because it lowers viscosities in the asthenosphere, enabling subduction. However, the following issue persists: if water is necessary for plate tectonics, but subduction itself hydrates the upper mantle, how is the upper mantle initially hydrated? In this paper, we propose that the processes of magma ocean solidification and overturn may add sufficient quantities of water to the upper mantle to encourage plate tectonics and, in turn, the habitability of Earth-like extrasolar planets.

On an Earth-sized planet a magma ocean would solidify to produce dense near-surface solids that contain the bulk of the interior water, held in the solid state. During gravitationally-driven overturn these solids sink deeper into the mantle and dewater. This event would have the potential to partially melt the upper mantle and to produce a damp asthenosphere.

The transition from magma ocean to modern-day plate tectonics is very poorly understood. The earliest part of this transition, however, was likely dominated by an enormous flux of extra-terrestrial bodies. The surface of the Hadean Earth was likely widely reprocessed by impacts through mixing and melting, and the earliest atmosphere would have been highly altered by this process.

Rather than approaching plate tectonics from the point of view of mantle convection, the problem may be thought of as the balance between brittle fault development and annealing. The maintenance of brittle faults is required to keep plates separate and able to move, and so both hotter mantles (as in young planets) and hotter surfaces (for example, Venus) will suppress plate tectonics. Venus may well be too hot to allow Earth-like plate tectonics to persist, and may either resurface volcanically periodically, or gradually and continually. Slow recycling, through dripping lithosphere, may be normal on one-plate planets. Such lithospheric dripping can produce both volcanism and volatile recycling.

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Interpretation of unrest in volcanic calderas

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Keywords: volcanic calderas, Campi Flegrei, Campania.

In volcanic calderas, it is not unusual to record long-term unrest's, with remarkable ground deformation, seismicity, and geochemical changes, that do not culminate in an eruption as shown by Campi Flegrei in 1982-1984. On the contrary, an unrest accompanied by minor geophysical changes can be followed in few months by an eruption, as in the case of Rabaul Caldera in 1994 and Sierra Negra in 2005. The development of new technologies in volcano monitoring in the last years has allowed the recording of unrest phenomena of several calderas with great detail. The main common features, among different calderas, are remarkable ground deformation with intense uplift episodes, that are often followed by subsidence. Often, the remarkable ground deformation in calderas indicates that the most probable cause of the unrest is a magmatic intrusions. In particular, this interpretation is almost univocal in the case of Rabaul and Sierra Negra calderas, which after the first unrest have undergone a second episode followed by eruption. About Campi Flegrei, in addition to the hypothesis of the intrusion supported by some authors, an alternative hypothesis related to the activity of the hydrothermal system has been proposed. Among the authors who invoke magmatic intrusion as the cause of the calderas' unrest, some have identified source geometries consistent with a sill or sill-shaped magma reservoir. Our hypothesis is that in general, the dynamics of calderas is primarily controlled by a mechanism due to the sub-horizontal intrusion of a sill-shaped magma body, which allows efficient magma storage and considerable deformation without necessarily triggering the magma transport toward the surface. On this primary mechanism, effects due to the hydrothermal system, viscoelastic behavior of the overlying rocks, or structural constraints may superimpose and can affect the dynamics of the volcanic calderas. In our model (Macedonio et al., 2014), the sill, fed by a deeper magma reservoir, intrudes below a horizontal elastic plate, representing the overlying rocks and expands radially. The model is based on the numerical solution of the equation for the elastic plate, coupled with a Navier-Stokes equation for simulating magma intrusion in the viscous regime. The numerical simulations show that during the feeding process, the ground is subject to uplift. When the feeding stops a subsidence occurs in the central zone. For very low flexural rigidity of the elastic plate, the subsidence can occur even during the intrusion of the sill. The stress field produced by the intrusion is mainly concentrated in a circular zone that follows the sill intrusion front.

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New data from the central sector of the Campi Flegrei to constraint the long term ground deformation pattern of the caldera

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Keywords: Ground deformation, Campi Flegrei caldera, faults, volcano-tectonic, paleoenvironment.

The Campi Flegrei caldera is an active volcanic field and one of the highly populated volcanic risk areas of the world. Due to presently changing in monitored parameters, as ground deformations, Civil Defence Protection has moved the caldera to at an attention level. A new detailed reconstruction of the relative movement between sea level and ground deformation of the central sector of the caldera has been carried out. The detailed stratigraphic and paleoecological study of key deposits sequence of La Starza marine fossil sea cliff allowed to reconstruct the paleoenvironment evolution of the area. The new excavation of a tunnel in the central sector of the Campi Flegrei caldera allowed us to collect new stratigraphic and structural data that further constrain the volcano-tectonic evolution of the last 15 ka. The analyzed sequences are composed by an alternation of volcanic, lacustrine/palustrine, fluvial and marine sediments hosting several deformation structures such as faults, sedimentary dykes and fractures. A review of available well log together with the new data were used to perform a 3D reconstruction of paleo-surfaces resulted after the main volcanic and deformation episodes. The measured structures indicate an extensional deformation accompanying the ground uplift occurred in various stages of the caldera evolution.

Stratigraphic relationships between structures and volcanic deposits further constrain the timing of the deformation phases. A significant submersion phase occurred in about 3.000 years between 8.5 and 5.5 ka during a sea level rise and was followed by an uplift of about 100 m between 5.5 and 3.5 ka, recording also a brief inversion around 4.5 ka. This vertical displacement represents the permanent recorded deformation linked with a volcanism period in which ~2 $km^3$of magma (DRE) were erupted by vents within the caldera. Furthermore we highlighted that the ongoing ground uplift larger than 3 m occurred since 1905/1907 shows a similar deformation pattern comparable to the normalized uplift shape of the unrest preceded volcanism at ~4.5 ka, supporting the main involvement of magmatic sources in ground deformation at Campi Flegrei caldera.

Presently an unrest phase of the Campi Flegrei caldera is marked by variations of different parameters such as ground deformation activities well recorded by GPS data, topographic leveling and satellite surveys. The results of this study provide further insight into the long term deformation pattern of the caldera and the ground deformation scenarios accompanying a possible resumption of volcanism.

Distribution of valleys, tectonics and volcanic features on Mars: insights on the formation processes during the evolution of the planet

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Keywords: Mars, channels, valleys, volcanoes, stratigraphy.

Mars is characterized by the absence of plate tectonics (O'Rourke & Korenaga 2012; Leone et al. 2014; Wong & Solomatov 2015) and by a low atmospheric pressure between 2-6 mbar (Guzewich et al. 2016), which does not allow the presence of liquid water on the surface. The planet lost much of its water in the pre-Noachian (Kurokawa et al. 2014; Krasnopolsky 2015; Villanueva et al. 2015) when the volcanism peaked immediately after the formation of the Martian dichotomy likely as a consequence of a giant impact on the south pole of the planet (Leone et al. 2014). The enormous energy of the giant impact produced the strongest volcanism, mainly distributed in twelve alignments, half of which starting from Tharsis (Leone 2016), the largest volcanic province with the longest lava channels of Mars. Kasei Valles and Valles Marineris follow the topography for thousands of km from their common source located at Labyrinthus Noctis with their sinuous lower courses. Here we focus on the integrated analysis of valley networks, deltas, volcanoes and tectonic features to investigate possible correlations among them at global and regional scales. The main aim of this study is to clarify and quantify the role of water for the formation of the valley networks considering also alternative hypotheses, such as the volcanic and/or tectonic origins. Preliminary results show that valley networks and deltas are mainly located in the equatorial regions (Di Achille & Hynek 2010), where the volcanic provinces are also located. Many valleys have radial patterns spreading directly from the volcanic centres and some other features, previously thought as of tectonic origin, have instead sinuous patterns that follow the topography. We are also investigating the chrono-stratigraphy of fluvial, volcanic, and tectonic features to identify possible formation relationships throughout the overall planet evolution.

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Geophysical investigation of Pleistocene volcanism and tectonics offshore Capo Vaticano (Calabria, southeastern Tyrrhenian Sea)

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Keywords: Tectonics, Submarine volcano, Aeromagnetic anomaly, Calabrian Arc, Aeolian Volcanic Arc.

Magma upwelling forming volcanic plumbing systems in back arc settings is typically controlled by exten-sional tectonic structures of the upper crust. Here we investigate this process in the area between the volcanic arc of the Aeolian Islands and the Calabrian arc (SE Tyrrhenian Sea) by integrating morpho-bathymetry and reflection seismic data with the outcomes of "Inverse 3D magnetic modeling" of previously gathered aeromagnetic data. Morpho-bathymetric data highlight the presence of a seamount~10 km offshore Capo Vaticano Promontory (eastern Calabria). This feature, named Capo Vaticano seamount is composed of a series of NE-trending ridges, the greatest of which (R1) is ~12 km long, and 2.4 km wide, displays asymmetric flanks with a landward steep slope, oblique morphological steps and elongated NE-trending rims. The position of the R1 ridge summit fits the Reduced-to-the-Pole peak of a high-intensity magnetic anomaly straddling Capo Vaticano Promontory and its offshore prolongation. Seismic and bathymetric data highlight two extensional fault systems affecting the offshore of Capo Vaticano Promontory during the Plio-Pleistocene: (a) a Pliocene NW-trending, SW-dipping normal fault system, and (b) a Pleistocene NE-trending, SE-dipping normal fault system. The younger system is composed of a series of en-echelon branching normal faults bounding the eastern side of the R1 ridge. Aeromagnetic data modeling imaged a complex 3D-magnetized body below the R1 ridge exhibiting a sub-vertical conduit-like structure in the shallow part, and a NE-striking, sheet-like shape inclined by 45◦indepth. The location of the sub-vertical conduit coincides with the summit of the R1 ridge. The magma uprising at the root of the volcano was controlled by the Pliocene NW-trending faults whereas its further upwards migration was ostensibly controlled by the Pleistocene NE-trending faults. Both fault systems are responsible for the high level of fracturing that likely favored the upward migration of magma. The younger extensional systems also controls the present-day, mantle derived, fluid escapes observed at the summit of the R1 ridge. Relying on seismic stratigraphic evidence as well as the normal polarity of the magnetic anomaly, the R1 ridge probably started to form during the Olduvai chron (early Pleistocene,1.81–1.96 Ma). Accordingly, the Capo Vaticano volcano may represent the result of magmatic activity that predates the Aeolian volcanic arc.

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(More than) fifty shades of plumes

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Keywords: Plume, basalt, petrology, geochemisty, mantle.

The mantle plume hypothesis (often used with the synonym “hot-spot”) is greatly changed from the original model proposed more than fifty years ago. In 1963 J. Tuzo Wilson proposed a ~200 km deep origin for the Hawaiian magmas, to explain the relative fixity of the igneous activity loci during the Tertiary and Quaternary (Wilson, 1963).

Less than ten years later, W. Jason Morgan proposed a much deeper origin to explain the relative fixity of volcanic island chains. Active solid-state mantle upwelling with a roughly 150 km diameter and a rising velocity in the order of few meters/year should be rooted in the lowermost mantle (Morgan, 1971, 1972).

Nearly twenty years later, simplified laboratory experiments demonstrated the possibility to develop mushroom-shaped features using liquids with different density and viscosity placed above a hot-plate with a long and narrow tail and a head diameter reaching 2000 km when scaled to natural conditions (Griffiths and Campbell, 1990).

Geochemistry was soon involved in defining and characterizing mantle plume sources (e.g., Hofmann & White, 1982; White, 2015). At the same time, using geophysical and geochemical arguments, a minor group of scientists strongly argued against the mantle plume model (e.g., Anderson, 1981; Foulger et al., 2005; Presnall and Gudfinnson, 2011; Lustrino and Anderson, 2015).

More than 50 different types of mantle plumes have been proposed in literature, e.g., thermal, fossil, channelled, toroidal, tabular, depleted residual, finger-like, recycled, edge, cold, cacto-, super, asthenospheric, dying, not very energetic, spaghetti, baby, head-free, splash, pulsating, subduction fluid-fluxed, refractory, hydrogen, heterogeneous, flattened onion, subduction-driving, subduction-triggered, washboard, bent-shaped, failing, delamination-triggering, concentrically-zoned, mushroom, laminar, advected, extinct, bilateral, bifurcated, geriatric, primary and secondary, accreted, diverted, deformed, golden, veined, hidden, weak, pulsing, young, blob-like, cavity, starting, passive, stealth, tilted, asymmetric, mega, mini, not-hot, killer, deflected, stripy, diamondiferous.

At the present, the power of geochemistry applied to basaltic magmas to identify the presence of mantle plumes results strongly reduced. Similarly, geophysics and seismic tomography have a too low resolution and are too much model-constrained to be considered the smoking guns to identify deep mantle plumes.

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The 2010 Eyjafjallajökull volcano eruption (Iceland): auto-mingling signatures in the basaltic products of the opening lava fountain phase

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Keywords: magma mingling, disequilibrium textures, magmatic processes.

The 2010 Eyjafjallajökull volcano eruption (Iceland) was characterized by a first phase (20 March-12 April) of basaltic effusive and lava fountain activity through a fissural eruption located on the eastern flank of the volcano, outside of the caldera border. This phase was followed by the summit explosive eruption started on 14 April which continued, with variable intensity, for 39 days. In this work we analyzed the basaltic scoria erupted during the opening lava fountain activity in order to evaluate how the volcanological and magmatological processes could have driven the initial phases of this eruption.

Selected samples are represented by both lava and scoria fallout of the fountaining activity. Petrography was performed by using polarized-light microscopy while morphological and geochemical data were obtained through SEM-EDS microanalysis.

Based on petrographic features, the analyzed samples are classified as porphyritic basalts, with a modal mineralogy consisting of plagioclase, olivine, clinopyroxene, and opaque minerals, in a hypocrystalline groundmass. Textural analysis emphasizes disequilibrium growths in phenocrysts (e.g. complex zonations in plagioclase and embayed structures in olivine) and rapid quenching (skeletal olivine textures). This evidence suggests changes in the chemical-physical conditions of the crystallization system or a mixing/mingling of different silicate melts. In addition, the basaltic scoria shows two different textures at the microscale: (i) - cryptocrystalline-hypoialine and (ii) - glassy, involved each other in convoluted and lobate-cuspate margins, thus suggesting liquid-liquid magma mingling process.

SEM analyses also allowed to separate the investigated scoria into glassy and cryptocrystalline-hypoialine portions, similar to what observed in thin sections. The glassy scoria would correspond to a homogeneous Fe-Ti-rich basalt, whereas the cryptocrystalline-hypoialine one shows a more variable composition.

Data obtained from this study suggest the presence of cooler regions, close to the walls of the magma-feeding dyke of the flank eruption, in which the basaltic melt started to crystallize in sub-volcanic conditions (cryptocrystalline-hypoialine portions). The convoluted and lobate-cuspate boundaries within the two different textures at the microscale portions in the scoria samples could be therefore due to thermal variations into the feeding basaltic dyke in pre-syneruptive conditions (auto magma mingling) of the opening lava fountain phase of the 2010 Eyjafjallajökull volcano eruption.

Geochemical, mineralogical and isotopic features of the melilitic rocks and associated mantle xenoliths in the Takarindoha lava field (Central-Eastern Madagascar)

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Keywords: Melilitites, Nephelinites, Mantle xenoliths, Madagascar.

The lavas of the Takarindoha district of Madagascar are olivine melilitites and olivine melilite nephelinites. These rocks have a primary olivine + clinopyroxene + melilite + spinel + nepheline +perovskite mineralogy. The mantle-normalized trace element diagram show marked enrichment in strongly incompatible elements and a trough at K, that is common to all Cenozoic mafic rocks of Madagascar. High initial ε_{Nd} values of +2 to +3.8 ($^{143}Nd/^{144}Nd$ = 0.51272-0.51282) is accompanied by low and constant $^{87}Sr/^{86}Sr$ ratios ranging from 0.7039 to 0.7041. Trace elements of melilitic rocks suggests that these rocks cannot be generated from a primitive mantle source, but rather from an incompatible element - enriched source. A high La/Lu_N (42-56) ratio suggests residual garnet in the source. Melilititic and nephelinitic rocks are the product of small degrees of partial melting (1–2%) of a peridotitic source enriched in strongly incompatible trace elements by CO_2-H_2O-rich fluids and melts. The source is probably located in the lithospheric mantle within the garnet-phlogopite stability field, at depths greater than 80km. The melilitites of Takarindoha have a significant presence of olivine and corroded clinopyroxene xenocrysts, and are associated with peridotitic mantle xenoliths (cpx-poor lherzolites, harzburgites and dunites). The modal content of olivine in cpx-poor lherzolite to dunite can be attributed to varible degree of partial melting. The Cpx modal content is consistent to degrees of partial melting higher than 18% according to spinel facies melt modes. However, the chemical composition of minerals is consistent with a much lower degree of melt extraction (~10%), with respect to that recognized by modal composition. Indeed the olivine and pyroxene with the highest Mg# values are observed in lherzolites, i.e. those with less depleted modal composition. Also, the spinels with the highest Al content are observed in dunites those with the low abundance of spinel and this is uncommon, as spinel is the major Al-hosting phase. These dunites may be also considered as mantle cumulates. The chemical mismatch between mineral and modal composition is commonly considered to be evidence of chemical modification of the peridotites due to reaction with migrating melts (melt-rock reaction). Based on thermo-barometric estimates, the xenoliths have been incorporated in a region of the mantle that is different from the source of the melilititic host-magmas, that on its way to the surface, sampled the upper mantle at ~ 60km, as common in the other xenolith localities of Madagascar.

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Modelling of Middle Triassic Monzoni Intrusive Complex (Dolomites, Italy): emplacement and geodynamic setting

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Keywords: Monzoni Igneous Complex, Ladinian magmatism, tectono-magmatic evolution.

The broader area of the Dolomites in Northern Italy has undergone a number of Permo-Jurassic tectonic and magmatic episodes, including volcanism and rifting of Permian and Early Triassic age; Late Ladinian magmatism and tectonics, while rifting and continental margin evolution followed in the Late Triassic-Early Cretaceous ages (Doglioni,1987; Bosellini et al., 2003). The Monzoni Igneous Complex (M.I.C), together with those of Predazzo and Cima Pape, represent the main Ladinian (Middle Triassic) intrusive products of the western Dolomites and form a significant magmatic feature in the Southern Alps. This contribution shows a preliminary analysis of the tectono-magmatic evolutionary model of the Triassic Intrusive Monzoni Complex intruding the Permo-Triassic sedimentary framework and consequently constrain the volume and internal architecture of the magmatic chamber. The sole dating available for Monzoni intrusion is back to 1960's indicating an age of 230 ± 8 Ma (Rb/Sr and K/Ar methods; Borsi & Ferrara, 1968). It is primarily composed of clinopyroxenite, olivine-gabbros, gabbros, monzogabbros, and monzonite, accompanied by an important number of shoshonitic basaltic dykes (Bonadiman et al., 1994). The N70E elongated shape of the Monzoni intrusion covers an area of about 6 km^2 and suggests that magma emplacement and fractionation were dynamically controlled by regional ENE-WSW transcurrent tectonics, active during the Triassic time associated with multiple tectonic features (flower geometries, block-faulting, en-echelon structures). In order to define the deformational evolution and relationship between the magmatic intrusion in the deforming crust, an experimental approach through sand-box analogue modelling technique is followed. The shallow (<7 km depth) Monzoni complex is estimated to be related with a high viscosity magma ($1.3*10^2$ Pa s; Bonadiman et al., 1994), which migrated upward driven by magma overpressure forces through active pre-existing structures, intruding and deforming the brittle (Permian crystalline-metamorphic basement, Val Gardena Sandstone, Contrin Fm., Sciliar Fm.) and ductile (Bellerophon Fm., Werfen Fm.) Permo-Triassic host-rocks. The Monzoni magmatic event provoked large collapses and synvolcanic tectonism while the volcanic products (pillow lavas, hyaloclastites) partially infilled the basinal depressions.

Mineralogy, geochemistry and petrogenesis of Nyiragongo and Nyamuragira volcanic rocks (Virunga Province D.R. Congo)

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Keywords: Nyiragongo, melilitites, Nyamuragira, basanites.

The Virunga Volcanic Province (VVP) lies close to the northern end of the western branch of the East African Rift System (EARS). Volcanism started about 11 Ma ago and continuing to the present. The two active volcanoes of VVP, Nyamuragira and Nyiragongo are located along the seismically active sector of the western rift. Nyamuragira (3058 a.s.l.) is a large volcanic shield characterized by alkaline rocks ranging from basanite to tephrite and rare transitional basalt. Nyiragongo is a stratovolcano (3469 a.s.l.) characterized by rock types such as melilitite, melilite nephelinite, pyroxene nephelinite, leucite nephelinite, leucitite and leucite tephrite. Samples include parasitic cones and lava fields of the volcanic complexes from 1938 products until now, and products of 2002 eruption sampled from the proximal vent area to the distal outcrops. Nyamuragira basanites and tephrites are porphyritic with phenocrysts of olivine and clinopyroxene. Basanites have MgO (12.05-13.60 wt.%), Cr (790-926 ppm) and Ni (245-309 ppm) contents within the ranges expected for mantle-derived liquids. The transitional basalts have higher MgO (> 15 wt.%), Cr (> 969 ppm) and Ni (> 750 ppm) than basanites. Such enrichment in these elements is due to excess of olivine phenocrysts. Nyamuragira basanites have Zr/Nb (3.9-4.0), Ba/Nb (11-12) and La/Nb (0.86-0.9) ratios typical of mantle or OIB values. The primitive mantle-normalized incompatible element patterns of Nyamuragira show peaks at Ba and Nb and smoothly decreasing normalized-abundances from Nb to Lu. The high La_n/Yb_n ratio (18) indicates that the Nyamuragira basanites are low degree partial melts of a slightly incompatible element-enriched mantle source in the garnet stability field. The least differentiated mafic rocks of Nyiragongo are melilite nephelinites and olivine melilitites. Melilite has akermanite composition, olivine ranges from forsterite-fayalite to kirschsteinite and clinopyroxene is diopside. All samples are feldspar-free. The composition of the glass is often rich in Ba content (up to 5 wt.% BaO). These rocks have higher CaO (~16.3 wt.%) and lower SiO_2 (~ 40 wt.%), MgO (8.7-9.1 wt.%) and compatible elements concentrations (Cr = 380-395 ppm; Ni = 155-169 ppm) than Nyamuragira basanites. Their incompatible element patterns are also more enriched than those of Nyamuragira basanites with high LREE/HREE ($La_n/Yb_n = 42$). The low Zr/Nb (2.1) of the olivine melilitites indicate that the Nyiragongo olivine melilitites are melt products of an incompatible element-enriched source. In addition, their low heavy REE contents suggest that they were generated within the garnet-peridotite stability field within the lithospheric mantle. The compositional variation within the Nyiragongo volcanic rocks was largely controlled by low pressure fractional crystallization of the observed phases.

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Deformation associated with shallow magma intrusions: an analog modeling perspective

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Keywords: Analogue Modeling, Magma Emplacement, Geothermal Energy.

Magma overpressure at the time of the emplacement at shallow crustal levels may lead to deformation (i.e. forced folding, fracturing and faulting) in the country rock, both at local and regional scale (e.g. Senger et al., 2015). Previous studies on magma emplacement and the evolution of caldera/resurgent domes in different tectonic contests were mainly addressed to the analysis of the structural evolution of the system, shape of intrusion in relation to parameters such as style of faulting, deformation rate, emplacement depth, etc; these studies rarely focused on the analysis of the brittle deformation of the overburden. To get insights into the latter processes, we reproduced and analysed in the laboratory the fracture/fault network associated with the emplacement of magma at shallow crustal levels. We used a mixture of quartz sand and K-feldspar fine sand as an analogue for the brittle crust, and polyglycerols for the magma. Polyglycerols represent promising new analogue modeling ductile materials, being capable of reproducing a wide range of experimental viscosities. The modeling apparatus is a modified version of that developed by Montanari et al. (2010), paper to which the reader is addressed for the scaling approach.

The models were able to reproduce complex 3D architectures of deformation resulting from magma emplacement, with different deformation patterns -invariably dominated by forced folding and associated brittle faulting/fracturing- resulting from variable parameters particularly magma viscosity. These results provide useful hints for geothermal researches. Fractures and faults associated with magma emplacement are indeed expected to significantly influence the distribution and migration of superhot geothermal fluids near the edge of the magma intrusion. These structures can therefore be considered as potential targets for geothermal or mineral deposits exploration. In this perspective, evidence from analogue models may provide useful geometric and conceptual constraints for the 3D seismic interpretation.

The research leading to these results has received funding from the European Community's Seventh Framework Programme under grant agreement No. 608553 (Project IMAGE).

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Formation by dike intrusion for Cerberus Fossae, Mars

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Keywords: Mars, dikes, graben, volcanism, hydrothermal alteration.

Cerberus Fossae (CF) is a system of fractures on Mars that extends for more than 1200 km. The fossae, which can be 2 km wide and 1 km deep, are oriented ~radially to Elysium Mons. Several hypotheses for the formation and modification of the fossae have been proposed: purely tectonic (e.g., Berman and Hartmann, 2002; Vetterlein and Roberts, 2010) and volcanic/magmatic (e.g., Mège and Masson, 1996; Head et al., 2003; Burr et al., 2002; Taylor et al., 2013; Pendleton, 2015). Here, we present evidence for the dike–dominated formation and/or modification of CF.

Landforms and/or topographic signatures can be used to distinguish between tectonic and dike-related formation mechanisms. Despite multiple lines of evidence for volcanic activity associated with the CF, diagnostic structures may have been destroyed or obscured by recent normal faulting (Keszthelyi et al., 2008), melting of abundant ground ice (e.g., Balme and Gallagher, 2009), and/or hydrothermal alteration of the fossae margins (e.g., Pendleton, 2015).

Recent analysis of CF geomorphology (Pendleton, 2015) reveals evidence for local hydrothermal modification near the fossae margins, indicative of long-lived interaction between dikes and ground ice. Depressions have been observed adjacent to fossae, as well as evidence of flow away from the fossae margins (Pendleton, 2015). Together with previous work, these observations form a coherent picture of the formation and modification of the structures at Cerberus Fossae that requires underlying dikes (Pendleton, 2015).

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Ground deformations of the Campanian Plain and the Neapolitan Active Volcanoes by Continuos GPS measurements

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Keywords: Tectonics, Ground deformation, GPS, Neapolitan Volcanoes.

Microearthquakes and Ground deformations are well known to be the most effective phenomena indicating transitions of active volcanic areas from rest to unrest. Unfortunately, the deformation pattern observed in a volcanic area is due to the interaction of regional tectonics and local magmatism. Against this background, the complexity of the three structural systems as Somma-Vesuvius, Campi Flegrei Caldera and Ischia Island, of the Neapolitan volcanic area, located in the Campania Plain Graben, makes it difficult to ascertain which part of the deformation is due to the magmatic source. The rising of magmatic bodies is related to the geodynamic processes that have generated the extension of the western edge of the southern Apennines, the opening of the Tyrrhenian Sea, the crustal thinning and formation of the Campania Plain Graben.

The horizontal GPS velocity field of the Italian peninsula, expressed with respect to the Eurasian plate, shows that in the Neapolitan area the deformation pattern does not agree with that observed in the Apennines. This discrepancy could be attributed to local stress sources, such as those which generated the Campanian Plain Graben and the pressure variation in shallow magma chambers, and/or to the different rheological behavior of the crust subject to tectonic forces. To evaluate each of these phenomena, we have analyzed GPS measurements in last decade, using datasets from about fifty continuous GPS stations of the NeVoCGPS (Neapolitan Volcanoes Continuous GPS Network) as well as RING networks, both operated by INGV and covering the Neapolitan volcanic area and Campania region respectively.

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Geophysical investigations along the Tyrrhenian shore of Calabria

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Keywords: Tectonics, seismics, earthquake tomography, aeromagnetic anomaly, Calabrian Arc.

The Tyrrhenian Sea is a widely investigated basin developed in the Mediterranean area within the frame of Europe-Africa convergence and Ionian plate subduction process (Faccenna et al., 2014; Orecchio et al., 2014 and references therein). Since the Late Miocene, extension within the Tyrrhenian Sea was associated with coeval shortening in the Apennines-Maghrebide orogen and progressive southeastward rollback of the Ionian subducting plate. In this framework both extension and widespread volcanism well represented by the Vavilov and Marsili basins and the Aeolian volcanic arc, are typical features of the Tyrrhenian Sea region. Several authors (De Ritis et al., 2010; Loreto et al., 2015 and references therein) have also recently documented the occurrence of a submarine volcanic structure in proximity of the Tyrrhenian shore of southern Calabria just near the Capo Vaticano promontory. Geophysical and geochemical data have provided new insights on the volcano-tectonic origin and geometry of this volcanic structure formed in the upper plate of the Ionian subduction system. On these grounds, the present study aims to investigate the southeastern portion of the Tyrrhenian Sea and the confining western Calabrian area by integrating new results coming from local earthquake tomography, high-resolution reflection seismic and magnetic data. The joint evaluation of the different results will allow to further refine the knowledge of the Capo Vaticano volcanic structure. Moreover, we aim to discuss the possible occurrence of further events along a wider portion of the western Tyrrhenian Calabrian side, extended in between 38° and 40° of latitudes, on the base of previously undetected geophysical anomalies, potentially related to volcanic-intrusive manifestations.

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The Codola eruption in the potassic-rich belt of the Southern Italy: new constraints on the eruptive dynamics and magma evolution

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Keywords: Campanian Plain, Codola, Somma-Vesuvius, petrology, volcanism.

The Campanian volcanic area is part of the potassic-rich Italian belt which developed west of the Apennine orogeny, subject to a main extensional regime. Among the Campanian volcanism, Codola plinian eruption occurred at ca. 34 ka bp after the widespread large-volume Campanian Ignimbrite eruption. At this stage an important changes in the both tectonic settings and magmatism likely occurred in the Campania region. Within this framework, the Codola eruption appears as one of the first important eruption at the Somma-Vesuvius that began to delineate as distinct volcanic system with respect to the Campi Flegrei caldera. The Codola tephra is a well-known tephro-stratigraphyc marker in many continental and marine archives and archaeological sites (Giaccio et al., 2008), although it's most proximal counterparts are poorly known. With the aim to fill the petrological gap, we conducted a detailed study of the most complete exposed sequence of the Codola eruption. The new dataset includes: texture from electron microscopy, mineralogy by X-ray diffraction, chemistry of phases by electron microprobe, whole-rock major and trace elements by X-ray fluorescence, and Sr and Nd isotope geochemistry of both bulk rocks and main phenocrysts. Few mineral-hosted melt inclusions allowed estimating volatile contents by Fourier Transform Infrared Spectroscopy. As result, we provide information on the eruption dynamics and the magma feeding system of an eruption occurred during the early phase of the Somma-Vesuvius growth, posing also the base to understand the relations between Late Pleistocene magmatism and tectonics within the Campanian plain.

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Oblique rift opening and fault reactivation revealed by episodic magma intrusions in central Iceland

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Keywords: Rifting event, dike, graben, InSAR, seismicity, faulting, Iceland.

Extension deficit builds up over centuries at divergent plate boundaries and is episodically removed during rifting events, accompanied by magma intrusions and transient meter-scale deformation. However, information on transient near-field deformation and on the relation between faults and magma during a rifting event has rarely been captured, hindering progress in understanding rifting mechanisms and evolution.

The 2014-15 Bárðarbunga rifting event in central Iceland was monitored with near real-time earthquake and geodetic observations, showing that it originated from the Bárðarbunga central volcano located under the Vatnajokull ice cap. Magma propagated over 40 km to the northeast from the central volcano and well beyond the periphery of the glacier where the intrusion eventually made it to the surface. It produced a 10 km long graben structure and a lava field of 1.5 km^3 leading to the largest eruption in Iceland for the last 200 years. Using radar image offsets, seismicity and structural field measurement we analyzed the spatio-temporal evolution of the event. We found new evidence of oblique rift opening influenced by pre-existing fractures and two centuries of extension deficit accumulation. Our results show that the opening was initially accompanied by left-lateral shear that ceased with increasing opening. It also suggests that the magma opened pre-existing fractures and propagated aseismically at shallower depths and that those rapidly opening fractures extended into the brittle-ductile boundary causing new fracturing and seismicity. Our findings directly challenge current dyke propagation models that classically do not consider pre-fractured medium. All together, our results strongly suggest that fault reactivation plays a key role in magma propagation at divergent plate boundaries.

Magmatic control along a strike-slip volcanic arc: the central Aeolian arc (Italy)

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Keywords: Volcanic arc, volcano-tectonics, strike-slip faulting, Aeolian islands.

Complex regional stress field in volcanic areas may be overprinted by that produced by magmatic activity, promoting volcanism and faulting. In particular, in strike-slip settings, the definition of the relationships between the regional stress field and magmatic activity remains elusive. To better understand these relationships, we collected structural, stratigraphic and volcanic field data along the strike-slip system of the central Aeolian Arc (Italy). There, the islands of Lipari and Vulcano separate the extensional portion of the arc (to the east) from the contractional one (to the west).

We collected >500 measurements of faults, extension fractures and dikes at 40 sites. Most structures are NNE-SSW to NNW-SSE oriented, with a dominant eastward dipping. Faults show almost pure dip-slip motion with minor dextral and sinistral shear, consistent with an East-West extension direction. Our data highlight six eruptive periods during the last 55 ka, which allow considering both islands as a single magmatic system, in which tectonic and magmatic activity steadily migrated eastward and currently focus on a 10 km long x 2 km wide active segment. Faulting appears to mostly occur in temporal and spatial relation with magmatic events, supporting that most of the observable deformation derives from transient magmatic activity (shorter-term, days to months), rather than from steady longer-term regional tectonics (10^2-10^4 years). More in general, the central Aeolian case shows how magmatic activity may affect the structure and evolution of volcanic arcs, overprinting any strike-slip motion with magma-induced extension at the surface.

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Structural and remote sensing analyses of the Somma-Vesuvius complex and the neighbouring carbonate mountains: insight into the interaction between volcanic (local) and tectonic (regional) stress fields

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Keywords: Somma-Vesuvio, structural analysis, volcano-tectonics.

Faults, fractures and volcanic dykes hosted in the Somma-Vesuvio volcanic complex have been analyzed. Structural data were collected within the SV caldera and in some quarries along the volcano flanks as well as in some key sector along the carbonate reliefs bounding the southern sector of the Campania plain. Furthermore morphological lineaments were detected from high-resolution (1m) DTM deriving from LiDAR data. Lineaments were identified after the analyses of multiple hill shades obtained by applying different pseudo-illuminations (from NW, NE, SE and SW) and appropriate filters to the original DTM. More than 8,500 orientation data of faults, fractures and dykes and 4,000 lineaments have been analyzed through rose diagrams and inversion methods. The structural analysis reveals a close interaction between volcanic (local) and tectonic (regional) stress fields. The analysis of lineaments indicate that most of them are radial with respect to the centre of the caldera with a secondary "tectonic" component mainly represented by the NNE-SSW, ENE-WSW and the well-known Apennine direction (NW-SE). Finally, preliminary results of faults hosted in the Cretaceous limestones of Campania Plain and the overlying Quaternary sediments reveal the occurrence of, at least, four sets: (i) early NE-SW and NW-SE faults (ii) E-W normal faults, probably related with the origin of Campania Plain and (iii) N-S normal and strike-slip faults that may have acted as transfer faults.

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Scan a volcano to reveal its interior deep structure: magnetotelluric imaging of the Campi Flegrei caldera (Italy)

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Keywords: Active volcanoes, Magnetotelluric, Fluid migration, Melt pathways.

Active volcanoes, and particularly caldera systems, are among the best studied geological structures of the Earth's crust. They are sites of great interest both for their geothermal and hydrothermal potential and for the volcanic risk. Many geological and geophysical methods can be used to identify the main structures from the surface to the first km in depth. Widely more uncertain is the definition of deep structures, in particular concerning with location and geometry of magmatic systems.

Among geophysics, Magnetotelluric (MT) is a broad-band electromagnetic technique which is used to image crustal structures in terms of resistivity from a series of simultaneous measurements of the fluctuations of the local electric and magnetic natural fields. MT is sensitive to electric conductivity anomalies associated with fluids and therefore it is particularly well suited to image fluid migration and melt pathways. MT represents, together with the seismic, the only geophysical prospecting method able to explore structures at the several kilometer depth scale. However, with respect to seismic prospectings, it is exceptionally less expensive and allow acquiring data in not favorable geological conditions .

An example of such capability is here presented, with an MT imaging of the Campi Flegrei caldera (CFc). The CFc is the most hazardous volcano in Europe (Orsi et al., 2004). Due to its destructive potential, enormous investigative efforts have already been done aimed to share the caldera structure and to understand its unrest dynamics. However, drilling explorations and geophysical surveys nowadays solved the main structures just down to 5 km, in terms of density and elastic parameters and although seismic findings of melt-bearing rocks exist, a clear understanding of the deeper feeding system of the CFc, has been by far not yet obtained.

We present the MT imaging of the CFc buried structures down to 10 km of depth across a 12 km-long profile ideally intersecting the principal structures of the caldera. The obtained results provide a key to interpret the caldera dynamics, playing hence a critical role for the assessment of the volcanic hazard and the risk mitigation at CFc. The findings confirms how MT could play a decisive role in the understanding of the deep structure of the volcanic areas, resolving the ambiguity unsolvable using other geophysical techniques.

SESSION S9

Input and output in subduction settings: chemical and geodynamics implications

CONVENERS AND CHAIRPERSONS

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Seismic versus aseismic behaviour of thrust faults of antigorite serpentine

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Keywords: Antigorite, frictional anisotropy, slip trajectories, crystal preferred orientation.

Antigorite, the high-temperature, high pressure polymorph of serpentine, is the most abundant hydrous phase within the upper mantle. It is responsible for the seismic shear-wave anisotropy measured in many subduction systems which is attributed to strain-induced lattice preferred orientation. This orientation phenomenon occurs in accordance to two mechanisms, depending on many factors among which we mention strain rate and fluid concentration. Both mechanisms drive the orientation of the antigorite (001) plane parallel to the shear plane (fault plane). However, one mechanism brings about a concentration of the a-axis subparallel to the shear direction, whereas the other mechanism brings about a concentration of the a-axis orthogonal to the shear direction (Katayama et al. 2009).

By an experimental analysis based on scanning force microscopy performed on (001) oriented antigorite single crystals (Campione & Capitani, 2013), we show that the basal surface of this mineral is characterized by a strong frictional anisotropy, reaching levels as high as 100%. Friction is observed to be higher along the a-axis and lower orthogonal to it, displaying an overall orthotropic symmetry in the sliding plane. By virtue of the aforementioned crystal preferred orientation, the shear interface of thrust faults, depending on the orientation mechanism, might be subjected to a hardening process or to a weakening process. The final result is that the fault might evolve as seismic or aseismic, respectively.

This seismic bivalence is not the only peculiarity stemming from the frictional anisotropy of antigorite. We show also that, in the framework of the said hardening process, slip trajectories might be substantially declined from the plate convergence direction.

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He isotopes in mafic phenocrysts from products of the Neapolitan Volcanoes (Southern Italy): constraints on the geochemical features of the mantle sources.

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Keywords: Neapolitan Volcanoes, helium, fluid inclusion.

In this work we present a study of helium isotope ratio R/R_a (where $R={}^3He/{}^4He_{sample}$, and R_a is the same ratio in the atmosphere) measured in Mg-rich olivine and clinopyroxene phenocrysts from a selection of mafic volcanic rocks of the Neapolitan Volcanoes (Vesuvius, Campi Flegrei, Ischia and Procida islands - Southern Italy). Helium isotope data of basalts from mid-ocean ridges, ocean islands, and subduction zones provide fundamental information on variable mantle source reservoirs. The R/R_a value of Mid Oceanic Ridge Basalts (MORB) is relatively uniform and shows a mean value of 8±1 (Kurz & Jenkins, 1981), while in Ocean Island Basalts it is more variable and may be either higher or lower than that of MORB, although the majority is higher (Graham, 2002). The R/R_a values of subduction-related basalts fall within a wide range from 8.8 in Colombian Andes (Sano et al., 1997) to 0.01, found at the transition between the east Sunda and Banda arcs in Indonesia (Hilton et al., 1992). The range of R/R_a values obtained on minerals of the Neapolitan Volcanoes (from 3,05 to 3,22) is comprised within the range of R/R_a values of fluids (fumaroles, hot springs, gas dissolved in water etc.) in the area (from 2 to 5.3; Tedesco et al., 1990, 1998). These data will contribute to enhance the He isotopes dataset for the Neapolitan Volcanoes, to date limited to very few data (Martelli et al., 2004). In order to improve the knowledge on the geochemical features of the mantle sources in the area and to identify the role of crustal contamination, the covariance between R/R_a in phenocrysts and the corresponding Sr isotopic composition in whole rocks for each unit will be investigated.

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The role of carbon from recycled sediments in the potassic magmatism of the Central Mediterranean region: evidence for carbonate metasomatism in the mantle

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Keywords: Central Mediterranean region, ultrapotassic igneous rocks, sedimentary carbonate recycling.

The Central Mediterranean region is one of the most important region on Earth for studying subduction-related potassic and ultrapotassic magmatisms, deriving from partial melting of the metasomatised lithospheric mantle wedge. Mediterranean ultrapotassic igneous rocks are intimately associated in space and time with shoshonites and calc-alkaline igneous rocks and genetically related with the mechanisms that driven the geodynamic evolution of the region. The petrological, geochemical, and isotopic features of the erupted rocks are thought to be derived from the recycling within the mantle wedge of subducted sediments characterised by variable amounts of pelitic and carbonate components. Accordingly, subduction drags a large amount of CO_2 into the Earth's interior, which is partly returned to the atmosphere by volcanism. Subducted CO_2 may dramatically affect the equilibria among peridotitic minerals (olivine vs. pyroxenes) changing their stability fields and hence their modal abundances. Trace elements in olivine in subduction-related mafic alkaline ultrapotassic rocks from Central Mediterranean region are used as a proxy to define mantle wedge mineralogy and metasomatic processes. Minor element concentrations, and in particular the high Li and low Ti of all the olivines, confirm a major role for recycled sediment in the generation of Italian ultrapotassic magmas. The distinct contents of Ni, Mn, and Ca in olivine reflect the bimodal character of silica-rich and silica-poor ultrapotassic Italian rocks and constrain two distinct mineralogical reactions between metasomatic agents and peridotite. Olivine chemistry from silica-saturated rocks reflects the reaction of silicate melts with the ambient mantle, with consequent consumption of olivine in favour of orthopyroxene. In contrast, the low-Ni, high-Mn/Fe of olivine crystallised from silica-undersaturated leucitites require a mantle source enriched in olivine (and clinopyroxene) compared to orthopyroxene, as a result of the interaction between the ambient peridotitic mantle and $CaCO_3$-rich metasomatic agents. The change from silica-oversaturated lamproites to silica-undersaturated leucitites and thus the difference in the olivine composition is due to a change in composition of the subducting sediment from pelitic to carbonate-rich. The results of this study provide new insights into how CO_2 is recycled via subduction processes deep into the mantle.

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Subduction cycle and mantle convection: clues from lithosphere volumes sinking at subduction zones

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Keywords: Subduction zones, recycling lithosphere, plate tectonics.

Subduction zones show a worldwide asymmetry that can be observed in slab dip, kinematics of the subduction hinge, morphology, structural elevation, gravity anomalies, heat flow, metamorphic evolution, subsidence and uplift rates, depth of the decollement planes, mantle wedge thickness, magmatism, backarc development or not, etc. This asymmetry could be easily explained if related to the geographic polarity of the sinking slabs. In fact, geophysical and kinematics constraints show that all the plates move “westward”. This preferential flow of plates would suggest a relative “eastward” mantle flow. If we look then to subduction dynamics within this set of conditions, this “eastward” mantle flow should have an important role in influencing subduction dynamics itself. Furthermore, along W-subduction zones slabs sink with a higher velocity with respect to the “easterly or northeasterly” directed ones. The faster “westerly” directed slabs determine that the volume of lithosphere recycled into this kind of subduction is larger than that along the converse ones (Doglioni and Panza, 2015 and references therein). Starting from this observations we attempted to estimate volumes of lithosphere that are currently subducting below the principal subduction zones. Moreover, we tried to look at these volumes with respect to the latitude of subduction zones, being plates velocities strongly linked to the Earth’s rotation. In fact, seismicity is latitude dependent and decreases with increasing latitude (Riguzzi et al., 2010; Varga et al., 2012).

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Sr-O-isotopic data on hybrid volcanic rocks of Arso, the last eruption occurred at Ischia island (Italy; 1302 AD)

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Keywords: Ischia island, Radiogenic and stable isotopes, Crustal contamination.

Origin and evolution of magmatic systems can be studied using geochemical and isotopic data. In particular, combined radiogenic and stable isotopes have proven to be an invaluable tool in igneous petrology and volcanology to understand magma sources and different-scale processes in open magma systems such as mantle enrichment, crustal contamination, and magma mingling/mixing. Understanding past behavior of the magma system feeding an active volcano is crucial also for volcanic hazards assessment. Ischia, an active volcanic field dominated by a resurgent caldera, located in the Gulf of Naples in South Italy, gives a good opportunity to investigate such processes. Furthermore, being a volcanic island in a densely populated area, it is prone to hazards. Geochemical and isotopic ($^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$) data have been acquired on whole rock and separated mineral samples from volcanic products of the 1302 AD Arso eruption, the last eruption occurred at Ischia island. The obtained results highlight petrographic and isotopic disequilibria between phenocrysts and their host rocks. Chemistry of the mineral phases, and $^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$ values suggest the occurrence of mixing processes between chemically and isotopically distinct batches of magma, and of a possible entrapment of crystals grown during an earlier magmatic phase. Similar disequilibria were highlighted also for more mafic volcanic rocks from Ischia and more in general from the Phlegraean Volcanic District products. The slightly radiogenic Sr isotope composition suggests that the mantle source was variably enriched by subduction derived sedimentary material. Furthermore, magmas extruded during the Arso eruption were affected by crustal contamination as suggested by the detected high oxygen isotope ratios. Assimilation and fractional crystallization modelling of the Sr-O isotope compositions indicates that not more than ~ 7% of granodioritic rocks from the continental crust must have been assimilated by a mantle-derived mafic magma. Hence the recent volcanic activity of Ischia has been fed by distinct batches of magma, variably contaminated by continental crust, that mixed during their ascent towards the surface and possibly intercepted phenocrysts left from earlier magmatic phases.

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Slab dehydration and deep water recycling through time

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Keywords: Slab dehydration Global water budget Numerical modelling.

We use a numerical tool that combines thermo-mechanical models with a thermodynamic database to examine slab dehydration for present-day and early Earth settings and its consequences for the deep water recycling. The fate of water in subduction zones is a key feature that influences the magmatism of the arcs, the rheology of the mantle, and the recycling of volatiles. We investigate the reactions responsible for releasing water from the crust and the hydrated lithospheric mantle and how they change with subduction velocity, slab age, and mantle potential temperature. Moreover, we investigate the implications for the water cycle throughout Earth's history.

Our results show that faster slabs dehydrate over a wide area: they start dehydrating shallower and they carry water deeper into the mantle. A hotter mantle (i.e., early Earth setting) drives the onset of crustal dehydration slightly shallower, but, mostly, dehydration reactions are very similar to those occurring in present-day setting. Moreover, we provide a scaling law to estimate the amount of water that can be carried deep into the mantle. We generally observe that a 1) 100°C increase in the mantle temperature, or 2) ~15 Myr decrease of plate age, or 3) decrease in subduction velocity of ~2 cm/yr all have the same effect on the amount of water retained in the slab at depth, corresponding to a decrease of ~$2.2x10^5$ kg/m^2 of H_2O. We estimate that for present-day conditions ~26% of the global influx water, or $7x10^8$ Tg/Myr of H_2O, is recycled into the mantle. Using a realistic distribution of subduction parameters, we illustrate that deep water recycling might still be possible in early Earth conditions, although its efficiency would generally decrease. Indeed, $0.5\text{-}3.7x10^8$ Tg/Myr of H_2O could still be recycled in the mantle at 2.8 Ga.

The Fe^{3+} partitioning in crust-derived fluid phases and implications for the slab-to-mantle element transfer

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Keywords: Redox budget, multiphase inclusions, subduction.

The redox processes taking place in the portion of the mantle on top of the subducting slab is poorly investigated and the oxidising (or reducing) power of crust-derived fluids phases is still unknown.

A case study of suprasubduction mantle affected by metasomatism from crust-derived fluid phases is represented by garnet orthopyroxenites from the Maowu Ultramafic Complex (China) deriving from harzburgite precursors metasomatised at ~ 4 GPa, 750 °C by a silica- and incompatible trace element- rich fluid phase. This metasomatism produced poikilitic orthopyroxene and inclusion-rich garnet porphyroblasts. Solid multiphase primary micro-inclusions in garnet display negative crystal shapes and infilling minerals (spinel, amphibole, chlorite, talc, mica) occur with constant volume ratios indicating that derive from trapped solute-rich aqueous fluids (Malaspina et al., 2006). The epitaxial relationship between spinel and host garnet, and between some hydrous minerals has been demostrated by single-crystal X-ray diffraction experiments (Malaspina et al., 2015). Epitaxy drives a first-stage nucleation of spinel under near-to-equilibrium conditions, likely promoted by a dissolution and precipitation mechanism between the UHP fluid and the host garnet. A second-stage nucleation involved hydrous phases, which nucleate in a non-registered manner and under far-from-equilibrium conditions. Imaging FT-IR and micro-Raman spectroscopy, together with X-Ray microtomography performed on single inclusions indicate that free water is still preserved in spinel-free inclusions.

To investigate the redox budget of these fluid phases, we measured the Fe^{3+} concentration of the microprecipitates of multiphase inclusions using EELS on a TEM. Results indicate that spinel contain up to 12% of Fe^{3+} with respect to total iron, amphibole about 30%, while inclusion phases such as chlorite and phlogopite may contain up to 0.70 of $Fe^{3+}/\Sigma Fe$. The $Fe^{3+}/\Sigma Fe$ of the host garnet has been measured both by Flank Method electron probe microanalyses and EELS and corresponds to 0.10. An oxygen mass balance between crust-derived fluids and the host rock indicates that fluid precipitates appear more oxidised than the host rock. This suggests that even after their interaction with the metasomatic orthopyroxenites, the residual fluid phases could be potentially carrier of oxidised components when escaping the slab-mantle interface.

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CO_2-fluid-rock interactions during subduction metamorphism of serpentinites

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Keywords: subduction, deep carbon cycle, CO2-fluid-rock interaction, carbonate, serpentinite, dehydration.

Given to its large relevance for present and past climate studies, the deep carbon cycle received increasing attention recently. However, there are still many open questions concerning total mass fluxes and transport processes between the different carbon reservoirs in the Earth's interior. One key issue is the carbon transfer from the subducting slab into fluids and rocks in the slab and mantle wedge. This transfer is controlled by the amount and speciation of stable carbon-bearing phases, which have a strong impact on the pH, redox conditions and trace-element budget of slab fluids. As recent experiments and thermodynamic modeling have shown, water released from dehydrating serpentinites has a great potential to produce CO_2-enriched slab fluids by dissolution of carbonate minerals. To constrain the fate of carbon and CO_2-fluid-rock interactions during subduction metamorphism of serpentinites, we have studied carbonate-bearing serpentinites recording different prograde evolutions from antigorite schists to Chl-harzburgites in high-P massifs of the Nevado-Filabride Complex (Betic Cordillera, S. Spain). Our results indicate that dissolution of dolomite in marbles in contact with dehydrating serpentinites is spatially limited during prograde metamorphism of carbonate-bearing serpentinites. In lower grade serpentinite massifs (La Milagrosa, Eastern Sierra de los Filabres; 1.0-1.5 GPa / 550 °C), the presence of marble lenses in contact with antigorite schists appears to promote local dehydration of serpentinite coupled with carbonation of antigorite, forming Cpx-TiCl-Chl-bearing high grade ophicarbonate zones. At the same locality, complex high temperature carbonation veins with Dol-Tr-Tlc-Chl assemblages occur along shear zones in serpentinite, which may provide evidence for an efficient entrapment of CO_2-rich fluids in serpentinites at depth. At the Cerro del Almirez ultramafic massif, where a dehydration front from antigorite-serpentinite to prograde Chl-harzburgite is preserved (1.9 GPa / 680 °C), a significant amount of carbon is retained in prograde Chl-harzburgites and marble lenses. Zoned banded marbles close to the contact to Chl-harzburgites comprise a high-grade assemblage with forsterite, Ti-clinohumite, diopside and chlorite, whereas forsterite is absent of diopside-marbles only a few meters away, indicating a water-dominated fluid induced metamorphism of marbles during serpentinite dehydration. Dolomite and calcite are commonplace in these marbles, while dolomite can also be found in tremolite-rich Chl-harzburgites close to the marble lenses. This observation is at odds with thermodynamic models that predict efficient carbonate dissolution during dehydration of carbonate-bearing antigorite serpentinite, and indicates that in natural systems substantial amounts of carbon can be recycled into the deep mantle via subduction of carbonate-bearing serpentinite.

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Seismic structure of the Northern Apennines: insights into subduction dynamics

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Keywords: subduction, Northern Apennines.

Subduction zones are the place in the world where fluids are transported from the foredeep to the mantle and back-to-the-surface in the back-arc. The subduction of an oceanic plate implies the transportation of the oceanic crust to depth and its methamorphization. Oceanic sediments release water in the (relatively) shallower part of the subduction zone, while dehydration of the subducted basaltic crust allow fluid circulation at larger depths. While the water budget in oceanic subduction has been deeply investigated, less attention has been given to the fluids implied in the subduction of a continental margin (i.e. in continental subduction). In this study, we use teleseismic Receiver Function (RF) analysis to image the process of water migration at depth, from the subducting plate to the mantle wedge, under the Northern Apennines (NAP, Italy).

Harmonic decomposition of the RF data-set is used to constrain both isotropic and anisotropic structures. Isotropic structures highlight the subduction of the Adriatic lower crust under the NAP orogens, from 35-40 km to 65 km depth, as a dipping low S-velocity layer. Anisotropic structures indicate the presence of a broad anisotropic zone (anisotropy as high as 7%). The crustal and upper mantle structures retrieved using RF analysis i compared to the original seismic data recorded during the CROP03 active seismic experiment to cross-validate our isotropic model and to provide a reference for the crustal structure in the Northern Apennines.

The anisotropic zone develops in the subducted Adriatic lower crust and mantle wedge, between 45 and 65 km depth, directly beneath the orogens and the more recent back-arc extensional basin. The anisotropy is related to the metamorphism of the Adriatic lower crust (gabbro to blueschists) and its consequent eclogitization (blueschists to eclogite). The second methamorphic phase release water directly in the mantle wedge, hydrating the back-arc upper mantle. The fluid migration process imaged in this study below the northern Apennines could be a proxy for understanding other regions of ongoing continental subduction.

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The Spiaggia Lunga mafic enclaves (Vulcano, Aeolian Islands): testimony of an older reservoir

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Keywords: Aeolian Islands, Vulcano, Mafic enclaves, Geochemistry, Sr-Nd-Pb isotopes.

The Island of Vulcano is part of the Aeolian Archipelago (Sicily, southern Italy). According to the outcropping rocks, the timing of volcanic activity at Vulcano ranges from ~120 ka to the present. Previous petrological investigations (De Astis et al., 2013 with references) showed first order geochemical differences between those products emplaced before or after 28 ka, the younger rocks being characterized by more silicic compositions and, afterwards, by enrichments in potassium and incompatible elements. Geochemical and isotopic studies demonstrated that the younger magmatism was not related to the older one through evolutionary processes such as FC, mixing or AFC, and a genesis from distinct parental magmas, which originated in a variably metasomatized enriched mantle, was suggested.

In the present study, a revision of geochemical and radiogenic isotope data from the volcanic sequence belonging to Primordial Vulcano (117-101 ka) up to the last eruption of 1888-90AD, as well as magmatic enclaves from volcanic units younger than 28 ka (Del Moro et al., 1998), was carried out and new data are presented on the Spiaggia Lunga enclaves and host rocks (24 ka). Magmatic enclaves from Gran Cratere di La Fossa lithosome (<5.5 ka) are latite to trachyte, as already highlighted by previous studies. They display major and trace element contents, and Sr-Nd-Pb isotope ratios within the range of Gran Cratere and La Fossa latites and trachytes. Their incompatible element patterns are basically similar to those of the youger volcanic rocks, with enrichments in LILE, depletions in HFSE, and negative spikes of Ba, Ta, P-Zr, and Ti.

Mafic enclaves from Spiaggia Lunga, already reported by De Rosa et al. (1988), have never been studied in detail before. Host rocks are shoshonitic basalts to shoshonites and are the most primitive among the younger products. Mafic enclaves are clinopyroxene-rich cumulates and monzogabbros. In the Harker's diagrams, where older and younger rocks show trends either differently sloping or sub-parallel, both Spiaggia Lunga host rocks and monzogabbroid enclaves plot along with the older rocks (>28 ka). The incompatible element patterns of monzogabbros mimic those of the older rocks, with lower enrichments in LILE, and deeper negative troughs of Ta and Zr, when compared to the younger volcanics. In the Sr-Nd-Pb isotope diagrams both monzogabbroid and cumulitic enclaves, along with host rocks, plot along with the older rocks. Summarizing, both mafic enclaves and host rocks of Spiaggia Lunga have many geochemical and isotope similarities with the >28 ka volcanic rocks and likely mark the persistence of an older, mafic reservoir during the first stages of development of La Fossa caldera.

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Experimental constraints on the composition of fluids interacting with a graphite-bearing, carbonate-free subduction melange

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Keywords: volatiles, carbon dioxide, high pressure.

CO_2 removal through dissolution of carbonates occurring in altered oceanic lithosphere and its sedimentary cover provides an efficient way to recycle carbon back to the mantle wedge. However, other forms of carbon, such as graphite, are closely associated with silicates in particular in subduction melanges. Graphite has been considered a refractory sink of carbon in the subduction slab, owing to its lower solubility in aqueous fluids compared to carbonates. However, graphite dissolution mechanisms and solute transport in complex COH fluids at high P are experimentally unconstrained. Estimates of CO_2 in subduction fluids are mainly based on traditional thermodynamic models, relying on a very limited experimental ground. Here we present for the first time experimental constraints on graphite-saturated H_2O-CO_2 fluids, synthesized at 1 GPa and 800Â° C conditions and redox buffered at $f$$H_2$FMQ and $f$$H_2$NNO, in equilibrium with i) graphite, ii) graphite + forsterite + enstatite (representative of the mantle component of the mélange) and iii) graphite + quartz (representative of sediments). Experimental fluids were analyzed for volatiles using a capsule-piercing device connected to a quadrupole mass spectrometer. In experiments bearing silicates, dissolved SiO_2 and MgO were measured using a modified version of the "cryogenic technique" by Kessel at al. (2005). At the investigated conditions, the CO_2 content in fluids exceeds the amounts retrieved by traditional thermodynamic models of ternary graphite-saturated COH fluids. Our results suggest that the interaction of deep aqueous fluids with minerals commonly found in subduction mélanges exerts a major role in controlling the volatile composition of the resulting COH fluid, enhancing the CO_2 content towards values unpredicted by thermodynamic models. As a consequence, the deep CO_2 transfer from the slab-mantle interface to the overlying mantle wedge, most favorable in cold subduction zones, where fluids are thought to be stable over melts, needs to be reconsidered.

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Sr-O isotope systematics in the Campi Flegrei magma systems

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Keywords: Sr-O isotopes, magma source, Campi Flegrei.

Combined radiogenic Sr- and stable O-isotopes help to distinguish between (a) contamination of mantle magma sources by fluids and subducted sediment and (b) assimilation of magmas during ascent through the crust. Advances in laser fluorination mass spectrometry allows to directly link Sr- and O-isotope measurements for small samples with high analytical precision.

We analysed mineral separates (feldspar, Fe-cpx, Mg-cpx, magnetite, olivine) from 37 samples covering the entire stratigraphic sequence of the Campi Flegrei volcanic field: oldest deposits underlying the Campanian Ignimbrite (Pre CI; >39.28 ka), Campanian Ignimbrite (CI; 39.28 ka), Post Campanian Ignimbrite/Pre Neapolitan Yellow Tuff (Post CI/pre NYT; <39.28 and > 14.90 ka), Neapolitan Yellow Tuff (NYT; 14.90 ka), and Post-Neapolitan Yellow Tuff (Post NYT; 12.8 ka-1538 A.D.) deposits. Sr isotopic compositions were determined using standard cation-exchange methods from separated hand-picked minerals (~300mg), and on whole rocks in case of not enough separated crystals. Oxygen isotope compositions were analysed by infrared laser fluorination on ~0.3 mg splits from the hand-picked phenocrysts.

Sr-isotopes span a range from 0.7069 to 0.7082 and exceed variations observed in bulk rock samples (0.7071-0.7081). However, these ranges vary significantly between eruptive periods. Similarly, recalculated δ^{18}O-melt values show a large range mostly between 7 and 10 ‰ VSMOW, with maximum and minimum values from ~11 to ~6 ‰ VSMOW. These compositions are very different from typical mantle values and span a large range towards heavy δ^{18}O values.

Comparing our new oxygen data with published O-isotope data on minerals from other Italian volcanic centers (Alban Hills, Mts. Ernici, Ischia, Mt. Vesuvius, Aeolian Islands, Tuscany and Sardinia) and from subduction zones worldwide (Kamchatka, Lesser Antilles, Indonesia and Central Andean ignimbrites) we can recognized distinct trends and sources: (1) serpentinized mantle (Kamchatka), (2) sediment- enrichment in the mantle source (Indonesia, Vesuvius), (3) magma assimilation by old radiogenic continental crust (Alban Hills, Tuscany, Ischia), (4) assimilation by mafic lower crust (Andes).

Sr-O-isotope values of Campi Flegrei and Vesuvius magmas fall on a single vertical trend in Sr-O isotope space that deviates profoundly from all other subduction-related magmas. This indicates that magmas are derived from (a) a mantle source variably modified by pelagic sediments (as for Vesuvius) and later (b) assimilated highly δ^{18}O-enriched crustal material that did not further significantly affect the Sr-isotope composition.

From Sr-O isotope relations, this crustal signal could be introduced through interaction with Mesozoic limestone, but no correlation is observed between δ^{18}O and Ca in whole rocks. Therefore, shallow assimilation of low-T altered volcanic material from previous volcanic activity in the Campi Flegrei caldera remains a possibility.

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Slab-mantle interaction during UHP and UHT metamorphism of garnet peridotites and their hosting crustal rocks (Monte Duria, Central Alps, N Italy)

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Keywords: Garnet peridotite, Adula nappe, crust-mantle interaction.

The Adula-Cima Lunga nappe complex is located on the eastern flank of the Lepontine Dome and represents the highest of the Lower Penninic units of the Central Alps. The Adula nappe chiefly consists of orthogneiss and paragneiss of pre-Mesozoic origin hosting lenses of metacarbonates, partly retrogressed eclogites and garnet/chlorite peridotites. The garnet peridotite bodies that crop out in the southern area of the nappe complex (Alpe Arami, Cima di Gagnone and Monte Duria) record the highest metamorphic conditions, with P exceeding 3.0 GPa at 800-850°C. In the study area garnet peridotite lenses are directly in conctact with biotite-bearing migmatites (ambient conditions of migmatization estimated at 0.5-0.7 GPa and 650-700°C) or hosted in amphibole-bearing migmatites and K-feldspar gneisses with boudins of variably granulitised eclogites and ultramafic enclaves.

Petrographic and minerochemical data provide evidence for a previously unknown UHT stage during peridotite and eclogite exhumation. Within peridotite, at former sites of Grt-Ol grain boundaries composite kelyphitic coronas made of opx after olivine and opx + cpx/amph + spl after garnet formed. Within opx after olivine, tiny crystals of baddeleyite (ZrO_2) and srilankite ($ZrTi_2O_6$) occur, suggesting the reaction olivine + rutile + zircon = opx + srilankite. Thermodynamic calculations in the system CFMAS $+ZrO_2$ $+TiO_2$ indicate that srilankite is limited to high-T conditions (900-1000°C) at pressure 0.8-1.2 GPa. Similar UHT conditions have been also determined for the granulitisation stage of eclogites. HP kyanite is here partly substituted by symplectites of pl(An_{84}) + spl + sapphirine ± corundum. The spinel-sapphirine Fe-Mg thermometer suggests T of about 850°C. Such high temperatures are also supported by the occurrence of HT phase assemblage within a Al_2O_3 rich layer (1-2 cm thick) sited along the rim of eclogitic boudins. This HT reaction rim clearly cut across the eclogitic foliation again pointing to a granulitisation stage that postdates the peak-P metamorphic stage.

Bulk rock analyses of peridotites show REE content 3 to 5 times lower than PM but with a clear enrichment in LREE and with a Eu positive anomaly. The same "spoon like" pattern in the LREE field is displayed also, shifted to values 2 to 5 times higher than PM, by eclogites. Due to the similarities of the REE patterns of peridotite and eclogite and the occurrence of the Eu positive anomaly in most of the peridotite analyses that points to a contamination by a "basaltic" source, we suggest that eclogites are the source of the metasomatic agent that enriched the original garnet peridotite.

The Monte Duria area thus represents a natural laboratory where is possible to study "in situ" the mantle-crust interaction. Metasomatic agents and processes, relationships between UHP-UHT metamorphism and metasomatism, and mechanisms of emplacement of mantle rocks into crustal slab can be here addressed and framed in the context of the well known geological background of the Alps.

SESSION S10

Controls of mantle depletion/enrichment on geological processes

CONVENERS AND CHAIRPERSONS

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Melt/rock reaction at the oceanic mantle-crust transition, through combined EBSD and in-situ mineral geochemistry studies on the Erro-Tobbio peridotites (Ligurian ophiolites, Italy)

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Keywords: Ligurian ophiolites, Troctolites, Melt impregnation.

Several lines of evidence have stressed that melt/rock reactions acting at the oceanic mantle-crust boundary play an important role in the chemical evolution of MORBs and the formation of the primitive (olivine-rich) lower oceanic crust. To address this issue, we performed detailed structural analyses and in-situ mineral geochemistry on the Erro-Tobbio (ET) ultramafic unit (Ligurian Alps, Italy), where impregnated mantle peridotites are primarily associated to an hectometre-size mafic body composed of troctolite to plagioclase-bearing wehrlite. The troctolitic body exhibits high complexity, with a host troctolite (Troctolite A) crosscut by troctolitic decametre-size pseudo-tabular bodies (Troctolite B). These different generations of troctolites show distinct modal compositions and textures. The host troctolite A displays a dominant millimetre-size corroded granular texture of olivine, a layering defined by poikilitic plagioclase enrichment, and rare occurrence of dunite pods. The contact between the mafic body and the host mantle peridotites is irregular, and defined by troctolite to wehrlite apophyses. The troctolite A shows microstructures and Crystallographic Preferred Orientation (CPO) indicative of a formation after impregnation of a mantle dunite by an olivine-undersaturated melt. This impregnation leads to olivine dissolution, associated with poikilitic plagioclase and clinopyroxene crystallization. This is indicated by a progressive randoming of the Axial-[100] CPO with olivine disaggregation and increasing melt input in the troctolite. The crosscutting troctolite B exhibits significant olivine textural variation, from fine-grained granular to deformed coarse-grained skeletal olivine. Olivine in the troctolite B shows CPO indicative of crystallization after magmatic flow, intrusive into the host troctolite A. Both troctolite types display large major and trace element variations in minerals, e.g. variation of Anorthite content (An = 54-67) in plagioclase at rather constant Forsterite content in olivine, and significant Zr, Ti, HREE heterogeneity in olivine, systematically correlated with the textural variability (e.g. corroded deformed vs. undeformed granular olivine. These features indicates that reactive crystallization had an important role in the origin of the ET troctolites. We infer that the textural heterogeneity of olivine in the troctolite B is related to variations in the degree of undercooling and cooling rate of the melt (Faure et al, 2003). The skeletal olivine crystallization could correspond to the influx of a more primitive melt into a colder host troctolite, followed by evolution of the melt leading to formation of fine-grained granular crystals. Overall, the results of this study suggest a poly-phase formation of this hectometre-scale gabbroic body, involving impregnation of a mantle-derived dunitic body followed by intrusion of undercooled primitive melts.

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The location of plagioclase-spinel and spinel-garnet transitions in a mantle pyroxenite: an experimental study from 0.7 to 1.5 GPa

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Keywords: Pyroxenites, experimental petrology, piston cylinder experiments, garnet stability, plagioclase.

Mantle peridotites exposed in ultramafic massifs are often veined by pyroxenitic lithologies that can be originated by deep magmatic infiltration, thus representing old heterogeneities in the mantle. These pyroxenites experienced the same metamorphic evolution of the host peridotites but they are expected to develop sensibly different phase assemblage at fixed P-T in response to bulk compositions significantly different from peridotitic rocks. Despite of several experimental studies focused on melting relations in various pyroxenites, very few experimental data are so far available for their phase relations at subsolidus lithospheric conditions (e.g. Adam et al., 1992). This study aims to provide new experimental constraints on phase stability and mineral chemistry in a natural pyroxenite from ophiolitic mantle sequence (Northern Apennine, Italy). This pyroxenite has a hybrid bulk composition, with relatively high X_{Mg} (0.83), high CaO (14.5 wt%) and low Na_2O (0.48 wt%) contents, that is peculiar of secondary pyroxenites originated by interaction between peridotite and pyroxenite-derived melt (Borghini et al., 2016). Experiments were conducted at pressure from 0.7 to 1.5 GPa, temperatures from 1100°C to 1250°C in piston cylinder apparata, on an anhydrous glass seeded with 1% of a mixture of synthetic pure spinel (50%) and garnet (50%). Al-rich spinel is stable in the whole investigated pressure range, as well as clinopyroxene, orthopyroxene and olivine. At 1100°C, a plagioclase-bearing assemblage is stable up to 0.9 GPa and a garnet-bearing assemblage is stable at 1.5 GPa and temperature between 1150 and 1230°C. The plagioclase appearance in the studied pyroxenite is moved at pressure slightly higher (0.1 GPa) than in fertile lherzolite (Borghini et al., 2010). At 0.8 and 0.9 GPa, plagioclase is slightly more anorthitic than in lherzolite and its modal abundances are about 12 and 8 wt%, respectively. We found few percent (5-6 wt%) of a pyrope-rich garnet in experiments at 1.5 GPa; at T = 1150-1230°C the garnet-in curve for this pyroxenite is rather flat and located at significantly lower pressure than mantle peridotites, expected to be above 1.8 GPa (Klemme & O'Neill, 2000). The compositions of pyroxenes vary significantly across the plagioclase-in and garnet in transitions and they are rather homogeneous in the spinel pyroxenite field, as result of negligible variability of spinel composition reflecting the very low X_{Cr} of the bulk (0.01). The results of our experiments are mostly well comparable to the mineral composition variability documented in natural samples and they can represent useful tools to trace the geothemobarometric evolution of tectonic mantle sequences.

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Relations between melt-percolation and deformation in the External Liguride mantle (Italy): a combined EBSD-(LA-ICP-MS) study

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Keywords: pyroxenite, peridotite, mantle deformation, melt-rock reaction, EBSD analysis, trace element.

Mantle lherzolites from the Northern Apennine ophiolites contain cm-thick pyroxenite layers that originated by rather deep (P > 1.5 GPa) and ancient (pre-Jurassic) infiltration of MORB-type melts (Borghini et al., 2016). Host peridotites locally display compositional banding (harzburgite and dunite) parallel to pyroxenite layers, and the whole layering is ubiquitously parallel to a well developed foliation. In spite of this deformation affecting the whole mantle sequence, previous work demonstrated that geochemical gradients are clearly recorded across the pyroxenite-peridotite contact and that the host peridotites have been modally, chemically and isotopically modified by reaction with melts percolating from pyroxenite veins (Borghini et al., 2013). Thus, we aimed to investigate the timing and interplay between melt-infiltration, melt-rock reaction and deformation by combining detailed in-situ mineral LA-ICP-MS analyses with EBSD observations. Along the pyroxenite-peridotite traverses, clinopyroxenes record systematic trace element variations: at the pyroxenite-peridotite contact they exhibit the lowest MREE-HREE abundances, with lower Sm/Nd ratios than the distal pyroxenite-free peridotites. The overall REE abundances progressively increase perpendicularly away from the pyroxenite-peridotite boundary up to about 20 cm, as a result of reactive porous flow at decreasing melt mass. Beyond 20 cm from the contact, the HREE content decreases with distance from the pyroxenite, while the LREEs remain at nearly constant level, pointing to a more efficient chemical buffering of the percolating melt HREE compositions by the host peridotite during ion exchange chromatographic-type processes. EBSD analyses on the same peridotite-pyroxenite profiles revealed well developed CPO of all constituent minerals. Olivine is basically [100]-fiber in every sample. Orthopyroxene and clinopyroxene CPO follows that of olivine, consistent with deformation by dislocation glide at moderate temperature. The combined evidence of well-preserved geochemical gradient across the pyroxenite-peridotite boundaries, and developed CPO in minerals of all lithologies, is best explained by a synkinematic formation of pyroxenites. This is also suggested by the CPO of clinopyroxene oblique to the foliation in some pyroxenites, consistent with low finite strains associated with crystallization during later stages of simple-shear deformation of the entire sequence. In addition, local enrichment in pyroxene and spinel in the peridotites close to the pyroxenite veins indicates that small amounts of melts were present in the peridotites during their deformation, corroborating melt infiltration in the host peridotites.

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Thermal and compositional effects of melting heterogeneous mantle sources along Mid Ocean Ridges

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Keywords: Mid Ocean Ridges, Abyssal Peridotite, Open system melting, Mantle heterogeneity, Melt/rock react.

Since the discovery of the parental relationship between oceanic abyssal peridotites and MORBs the processes in the suboceanic mantle have been assumed as nearly steady-state. These models match the general trend of both products and residues but cannot explain the significant scatter measured along the Mid Ocean Ridges. Recent discoveries show a multiscale variability of mantle processes in both space and time (Cipriani et al., 2009; Seyler et al., 2011). The source can be approximated by a mix of ultradepleted, fertile and ultrafertile lithologies arising questions on melting across the garnet/spinel transition and energy conservation in the adiabatically rising mantle. I present here new data from the ultraslow Smoothseafloor region (SWIR): the nearly-amagmatic end-member of the MOR system (Sauter et al., 2013). Melting low-solidus heterogeneities across the garnet/spinel field boundary leads to an inverse fractionation enriching the mantle in the most incompatible elements (Brunelli et al., 2015, 2014) and reproducing the Na metasomatism frequently observed in the subcontinental mantle xenoliths (Ponce et al., 2015). These processes are partly responsible of the enormous isotopic scatter of a mantle parcel with respect to the associated basalts. A phenomenon also reported for the formation of secondary pyroxenites in ophiolitic terrains (Borghini et al., 2013).

The most striking effect of melting a heterogeneous source appears when comparing mantle residua and melting products. During melting heat is transferred from the host mantle to the low-melting heterogeneity. As a consequence the host fertile mantle cools down subsequently delaying the onset of melting and deepening the thermal boundary layer. As a result the melting indicators of mantle and associated MORB countertrend in a time series when low-melting lithologies are present in the source. This effect also extends to trace and isotopic distribution. Isotopes in MORB appear to be representative of the low-melting lithologies while the isotopic distribution of the residue depends on short-scale processes resulting in an increase of the mantle heterogeneity at each melting event during geological times.

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Geometry and connectivity of hydrous-carbonatitic liquids in the mantle: an experimental model

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Keywords: Dihedral angle, Peridotite, Experiments, Hydrous Melts.

The mobility and infiltration rates of carbonatitic liquids, together with their influence on the annealing of mantle peridotites, are processes poorly constrained. Although natural carbonatitic magmas are complex chemical systems, bearing H_2O as a major chemical component, previous work has been performed in anhydrous model systems. The aim of this work is to quantitatively assess the variables controlling the percolation of hydrous carbonatitic liquids in peridotites, and their bearing on the mobility of melts.

The percolation of melts and the interconnectivity of melt pockets are investigated by placing a cylindrical dunite rod against a liquid reservoir. Thick graphite cylindrical inner capsules control the redox conditions and prevent Fe-loss to the outer Pt capsules. We used a synthetic dunite, pre-sintered in a Mo capsule starting from natural San Carlos olivine, previously sieved to 38-64 µm. Sintering has been performed in a single stage piston-cylinder apparatus at P = 0.8 GPa and T = 1200°C. As natural carbonatitic magmas in equilibrium with a mantle assemblage are mainly dolomitic, the composition ($Ca_{0.541}$, $Mg_{0.389}$, $Fe_{0.069}$) CO_3 was prepared from a powder mixture of carbonates, using free water as hydrous source (5 wt.% of mix). Time resolved experiments were performed employing an end loaded piston-cylinder apparatus, at T= 1200°C, P = 2.5 GPa and run times from 3 to 300 hours, according to the experimental phase diagram retrieved by Tumiati et al. (2013). In order to account for the different roles of gravity, chemical diffusion, and Ludwig-Soret diffusion we used two different geometries, first placing the dunite rod at the top of the capsule above the carbonate mix, then reversing the stack to have the carbonate mixture at the top, hot end of the capsule.

Hydrous carbonatitic melt pockets (> 3 µm) were found along olivine grain boundaries. BSE images and X-ray maps of elements allow quantifying the dihedral angle between the liquid and olivine. The apparent dihedral was measured through a Mathematica™ routine based on X-ray maps of elements. A true dihedral angle was estimated by the median of frequency distribution of the apparent angles. The results of approximately 400 measurements (for run durations of 300 hours), 130 meas. (for 30 hours) and 300 meas. (for 3 hours) provide a dihedral angle of ~40°, ~34°and ~31° respectively. These values are larger compared to the dihedral angle found for anhydrous carbonatitic liquids (25°-28°, Hunter & McKenzie, 1989). The volume fraction of melts in the peridotitic matrix was ~16% and ~2.3% for 300 hours experiment, the larger volume proportion retrieved close to the carbonatitic reservoir; ~10.5% for 30 hours experiment, and ~8.5% for 3 hours experiment. These values are significantly lower than those observed in anhydrous experiments (e.g. 18% in Hammouda & Laporte, 2000), therefore grossly in agreement with the relatively high dihedral angle measured (Park & Yoon 1985).

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Volatile content and geochemical features of the lithospheric mantle beneath Handler Ridge, Northern Victoria Land (Antarctica)

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Keywords: volatiles, noble gases, mantle xenoliths, Antarctica.

A geochemical study of ultramafic xenoliths from Handler Ridge (HR), Northern Victoria Land, is ongoing in order to investigate the characteristics of the lithosphere mantle beneath the Western Antarctic Ridge System (WARS).

The majority of the samples is spinel anhydrous lherzolites with rare presence of secondary phases (secondary cpx and glass). Geothermobarometric calculations, based on the Fe/Mg distribution among the peridotite phases, reveal that HR Sub Continental Lithosphere Mantle (SCLM) records temperatures always higher than 1000 °C and fugacity conditions close to QFM or higher (P fixed at 15 Kbar). This mantle domain represents a residuum after ~7 to 18% of partial melting in the spinel stability field, which was variably affected by interaction with a lithospheric alkaline melt that was able to modify the chemical composition (i.e. systematic enrichment in LREE in cpx) of the mantle, but not the modal proportion of the mineral phases (Pelorosso et al., 2016).

Elemental and isotopic abundance of noble gases (He, Ne, Ar) entrapped in fluid inclusions (FI) from HR olivine crystals was determined by crushing technique. He, Ar and Ne concentrations range between 7.97×10^{-14}-7.89×10^{-13}, 4.09×10^{-13}-4.99×10^{-12} and 1.70×10^{-15}-9.89×10^{-16} mol/g, respectively. The $^{4}He/^{40}Ar^{*}$ ratio corrected for atmospheric-derived contamination is quite homogeneous and ranges between 0.22 and 0.39. Total Gas Content of FI ranges between 7.08×10^{-10} and 3.08×10^{-8} mol/g, which in the assumption of a CO_2-dominated gaseous matrix gives information on the CO_2 concentration. The $^{3}He/^{4}He$ varies between 7.09 and 20.18 Ra (where Ra is the $^{3}He/^{4}He$ ratio of air), being the highest values measured in those samples with the lowest He concentration. The samples with $^{3}He/^{4}He$ higher than 9 Ra are probably affected by the addition of cosmogenic ^{3}He, whereas those with an helium isotopic ratio between 7.09 and 8.9 Ra are compatible with a mantle signature as also evidenced by the average $CO_2/^{3}He$ values of 2.0×10^{9} measured into the FI (Sano & Marty, 1995). Finally, the $^{4}He/^{40}Ar^{*}$ ratios (0.22-0.39) lower than the typical production ratio of the mantle ($^{4}He/^{40}Ar$=1-5; Marty, 2012) suggest that the pristine signature could have been modified by partial melting processes in agreement with major and trace elements geochemistry of opx, cpx and sp.

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Slab-melt metasomatism and refertilisation in Southern Carpathian upper mantle

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Keywords: Slab-melt metasomatism, Slab-melt refertilisation, upper mantle, Southern Carpathian.

A set of 40 ultramafic mantle xenoliths from Eastern Transylvanian Basin were collected to highlight the influences of subduction-related fluids/melts in the mantle wedge beneath the Southern Carpathian arc region. Samples were taken in lava flows and pyroclastic deposits of Persani Mts. where emission of Na-alkalic basaltic magmas occurred from Early to Middle Miocene, with two main stages at 1.6-1.0 Ma and at 0.6 Ma. This volcanism was immediately subsequent and even contemporaneous with the late calc-alkaline, adakite-like magmas of South Hargita Mts., in a regional geodynamic context of asthenospheric upwelling after slab tearing and retreatment. The xenoliths consist of harzburgites, ol-clinopiroxenite, ol-websterite, wehrlite and lherzolites, these latter with modal cpx and spinel content sometimes exceeding 18% and 4%, respectively. Among the peridotites, the prevalent petrographic textural type is transitional protogranular-porphyroclastic (40%), followed by porphyroclastic-foliated (25 %), porphyroclastic s.s. (21%) and protogranular s.s. (18 %). Amphibole is abundant, mainly as disseminated crystals (amph-D) associated with cpx, opx and (to a lesser extent) spinel, or, more rarely, as veins (amph-V). Reaction textures are widespread and in the majority of the cases no host basalt infiltration can be envisaged. Secondary phases (ol2, cpx2, sp2) and glass are present within patches associated with primary opx, cpx and sp and with amph-D. The analysed samples have been divided into two groups, based on their emission center (EMC1 and EMC2). EMC1 ol1 and opx have slightly lower mg# than the same phases in EMC2 (88.9-90.5 vs 89.7-91.8 for ol and 89.1-90.8 vs 89.6-92.1 for opx). Similarly, mg# of EMC1 cpx1 is lower than that of EMC2 cpx1 (89-90.8 vs 89.6-93); EMC1 cpx1 tend also to have higher Al2O3 contents (4.92-11.1 wt%) than EMC2 cpx1 (3.27-8.12 wt%). Cpx2 have higher Al_2O_3 contents with respect to cpx1. Amphibole mg# span from 86.5 to 88.5 in EMC1 and from 88.1 to 89.5 in EMC2. Their Al_2O_3 and Na_2O contents are similar in the two localities; K2O in EMC1 ranges from 0.08 to 1.34 while is always below detection limit for EMC2 amphiboles. Among amphiboles, amph-V have lower Al_2O_3, and Na_2O and higher CaO and K_2O values with respect to amph-D. Glass major element compositions resembles that of experimental and natural adakitic magmas and is very similar to the composition of the adakite-like magmas of South Hargita Mts. Chondrite-normalized REE patterns of cpx1 indicate that they underwent 4-14% of partial melting in the spinel stability field before being variably enriched [(La/Yb)N up to 5.5]; cpx1 enrichments seems to be related with amphibole modal content. A peculiar positive Eu anomaly in cpx1 are shown by the majority of the samples. Trace element patterns of amph-D vary from depleted to enriched types [(La/Yb)N = 0.3-5.9], these latter mainly differing for higher LREE, Nb and Ta contents. Amph-V have the most enriched patterns, with M-HREE content higher than of amph-D. In the discrimination diagrams proposed by Coltorti et al. (2007), amph-V fall into the intraplate field, whereas the majority of amph-D fit the suprasubductive field, highlighting the probable role of slab-melt/fluids in metasomatizing and refertilizing the Southern Carpatian upper mantle.

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The role of melt-rock reaction in Olivine-rich troctolite origin at mantle-crust transition: an experimental study up to 0.7 GPa

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Keywords: melt-rock reactions, olivine-rich troctolite, mantle-crust transition zone, experimental petrology.

Melt-rock reaction processes are inferred to play an important role in the origin of olivine-rich troctolite at mantle-crust transition in oceanic spreading lithosphere. We performed reactive dissolution and crystallization experiments at pressure ≤ 0.7 GPa in a piston-cylinder apparatus to provide experimental constraints on textures and mineral chemistry variations of melt-rock reaction products. Experiments are carried out by using salt-Pyrex-graphite-magnesium assemblies and graphite-lined platinum capsules. Experimental charges are prepared with three layers superposed from the bottom up: (1) basalt glass powder, (2) fine powder of San Carlos olivine (Fo90) as dunite analog, and (3) vitreous carbon spheres, used as a melt trap. In order to investigate the effect of melt composition, three synthetic MORB-type glasses have been used, two tholeiitic basalts and a primitive one (X_{Mg}=Mg/(Mg+Fe^{tot})=0.62, 0.58 and 0.74 respectively). Experiments have been performed at 0.5 and 0.7 GPa, at temperatures from 1150 to 1300°C, at both step cooling and isothermal conditions for different run durations (12-72 hrs.). Step cooling experiments resulted in layered samples in which all the initial San Carlos olivine reacted with the melt generating different lithologies from olivine-gabbro to olivine-rich troctolite (ORT). ORT has a poikilitic texture with rounded, lobate and euhedral olivine and interstitial poikilitic plagioclase and clinopyroxene; these latter showing mutual sharp contacts. Similar textures of resorption and recrystallization are observed in natural samples. Olivine shows significant chemical variations as a function of distance along the experimental sample; it ranges from Fo85 at the olivine-gabbro/ORT transition, i.e. the original melt-dunite interface, to Fo90 in the major part of the ORT layer far away from the original interface. Clinopyroxene shows X_{Mg} ranging from 84 to 90 from olivine-gabbro/ORT interface toward the ORT, plagioclase composition is An75 close to the interface, decrease along the ORT layer reaching An52. Chemical variations are observed also in the melt recognized as trapped phase all along the capsule, and not only within the vitreous carbon spheres at the top of the charge. Melt display an increase of X_{Mg} value from the bottom to the top coupled with a CaO/(CaO+NaO) decrease. In isothermal experiments only olivine and an interstitial melt are present, giving clues on the melt rock interactions that originate troctolites. Furthermore, reacted melts have been successfully trapped in the carbon spheres. They show, as expected, an increased X_{Mg} compared to the starting material (e.g. from X_{Mg} 0.62 to 0.73). Textures and mineral chemistry obtained in the present experiments are discussed in the light of natural occurrences in oceanic and ophiolitic environments.

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The role of volatiles in the genesis of Cenozoic magmatism in Northern Victoria Land (NVL), Antarctica

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Keywords: Mantle, primary magmas, volatiles, C-O-H, melting modeling, melt inclusion, Antarctica.

This study offers an innovative view of the petrogenetic processes responsible for the magmas erupted in the Western Antarctic Rift System (WARS) by studying the chemical composition and the volatiles content of basic lavas and olivine-hosted melt inclusions (MI). Lavas come from three localities: Shield Nunatak (Mt. Melbourne), Eldridge Bluff and Handler Ridge. They are olivine-phyric basanites (42.41-44.80 SiO_2 wt%; 3.11-6.19 Na_2O+K_2O wt%) and basalts (44.91-48.73 SiO_2 wt%; 2.81-4.55 Na_2O+K_2O wt%) with minor clinopyroxene and plagioclase. Samples from Handler Ridge clearly differ by having the highest TiO_2 (3.55-3.65 wt%), Rb, Ba, Nb, La, Zr despite their more primitive features (60.83-44.87 Mg#, MgO/(MgO+FeO) %mol). Olivine-hosted melt inclusions (MI) were analyzed for major element and volatiles (H_2O. CO_2, S, F, and Cl) after HT (1300°C) and HP (6 kbar) homogenization. Despite a larger variability, MI are compositionally comparable to the host lavas and are characterized by two distinct trends (high-Fe-Ti-K and low-Fe-Ti-K). The H_2O content in MI ranges from 0.70 wt% to 2.64 wt% and CO_2 from 25 ppm to 341 ppm (H_2O/CO_2~ 1). At comparable H_2O contents few samples show an higher CO_2 values (1322 ppm to 3905 ppm) with a H_2O/CO_2 down to 0.8. F and Cl content varies from 1386 ppm to 10 ppm and from 1336 ppm to 38 ppm respectively. Concentration of volatiles show a good correlation with alkalies, especially with K_2O; Handler Ridge presents the highest total value of F and Cl (2675 ppm). Chondrite-normalized trace elements concentration in MI show a intraplate pattern with negative anomalies in Rb, K, Ti. Acconrdingly to the lava contents, MI from Handler Ridge have a significant higher concetration in Rb (12-45 ppm), Sr (700-834 ppm), Ba (433-554) and Nb (48.8-83.4 ppm) with respect to the other localities at comparable Mg#. Mantle melting mass balance calculations simulate the observed H_2O, CO_2 and Cl concentration by melting a spinel lhezolite from 3 to 7 % of melting (F) with a 5% of modal amphibole with the same composition and modal proportion of mantle xenoliths from Baker Rocks, a locality near to Shield Nunatak. The model was not able to predict the F content which is less concentrated in natural sample. From the resulted partial melting percentage we calculated a total amount of CO_2 in mantle source of 273 ppm by assuming the highest 3900 ppm measured in MI as starting value. The estimated maximum content of H_2O and CO_2 in the primary melt is 2.6 wt% and 8800 ppm respectively. Obtained data were compared with those from mantle xenoliths from NVL with the aim to reconstruct the composition of the mantle source of the Cenozoic magmatism and to model the whole volatile budget from mantle to magmas starting from the measured volatile content in hydrous (amph) and NAM phases in mantle xenoliths. Preliminary results evidence that high-Fe-Ti-K basanites found in MI are very similar to the calculated metasomatic agent involved in the formation of the very peculiar Fe-rich lherzolites.

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Feedback of reactions on ductile strain localization in the shallow subcontinental lithospheric mantle

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Keywords: mantle, reaction, fluid, ductile strain localization, deformation.

Rock deformation in response to forces in the Earth's interior is governed by rheology, which varies as a function of constitutive and environmental aspects including mineralogy, fluid content and chemistry, melt fraction, temperature, pressure, differential stress conditions, and grain size. Accommodation of deformation typically results in an heterogeneous distribution of strain, eventually leading to strain localization, which enormuosly influence the strength of larger rock bodies and, at the lithosphere scale, it is crucial for the generation of plate tectonics from mantle convection. The understanding of the modes of ductile strain localization in the upper mantle is therefore of utmost importance in developing adequate rheological models and numerical simulations of the strength of the Earth's lithosphere.

Here we focus on the feedbacks of synkinematic net transfer reactions and free fluids on ductile strain localization in the shallow subcontinental lithospheric mantle. We report microstructural evidence for fluid-assisted ductile strain localization in mylonitic to ultramylonitic peridotite and pyroxenite shear zones that have been formed at low pressure (mm). We therefore suggest that focusing of aqueous fluids in the peridotite shear zone favored the activation of dissolution-precipitation creep and we propose that this deformation mechanism may be important in intermediate temperature domains (delimited by the stability of hydrous phases and the wet melting reactions) of subduction zones, where it may lead to feedbacks between strain localization and fluid transport.

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The role of percolating melts in the Northern Victoria Land lithospheric mantle (Antarctica)

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Keywords: mantle xenoliths, refertilisation, metasomatism.

The petrology of anhydrous (Greene Point, Handler Ridge) and amphibole-bearing (Harrow Peaks, Baker Rocks) xenolith populations from Cenozoic volcanics of Northern Victoria Land (NVL), Antarctica, provide new geochemical/geodynamic constraints on the nature and evolution of the NVL lithospheric mantle beneath a large area: from Mt. Melbourne (73°46,186'S, 165°57,003E') to Handler Ridge (72° 31'S 167° 18'E).

On the basis on mineral major and trace element modelling, this mantle domain represents a residuum after 10 to 20% of partial melting. Moreover, elemental and isotopic modelling evidence the large geochemical contribution of melts (tholeiitic and alkaline types), acting in different times, from at least Jurassic to Cenozoic. The close correlation between Greene Point clinopyroxene trace element contents and those from Ferrar tholeiites, allows to ascribe the first refertilisation event to the Jurassic Ferrar magmatism; this asthenospheric melt was also able to transfer a garnet signature to some NVL mantle segments.

Evidences of alkaline metasomatism are observed in all the studied localities, in fact the rare presence of glassy patches and related secondary phases in Greene Point and Handler Ridge, as well as the amphibole presence in Harrow Peaks and Baker Rocks xenoliths proves that alkaline metasomatism, probably related to the West Antarctic Rift System opening, heterogeneously affected the NVL lithospheric domain.

The modelling of the infiltrating agent acting in Handler Ridge lithospheric mantle reveals that metasomatism occurs just before xenolith's rising. In a time range of ~ 200 years' equilibrium with an alkaline melt is reached over a distance of 1 mm.

Geothermobarometric calculations based on the Fe/Mg distribution among the peridotite phases show that, at P of 15 Kbar, the presence of amphibole does not influence the ambient redox conditions (amphibole-bearing and anhydrous Greene Point peridotite, show similar fO_2 values: -0,7 QFM), but the anhydrous suite presents systematically higher temperature (950-1050 °C) than those of amphibole bearing population (850 °C).

Moreover, fugacity values calculated on the basis of the oxy-amphibole equilibrium reveal a strong disequilibrium of amphibole with the primary peridotitic paragenesis (i.e. Harrow Peaks) (+7 QFM; Gentili et al., 2015) with respect to those obtained by the ol-opx-sp equilibrium (from -2.78 to -0.24 QFM), suggesting that amphibole is in an early stage of its formation. This discordance of redox condition is not detected at Baker Rock (Bonadiman et al., 2014), where amphibole is clearly in equilibrium with the primary mineral assemblage, confirming that Harrow Peaks lithospheric mantle records an early stage of metasomatic melt-peridotite interaction.

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Multi-stage mantle melting and magma generation in the Albanides-Hellenides supra-subduction zone ophiolites

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Keywords: Ophiolite, Mantle peridotite, Basalt, Petrogenesis, Tectono-magmatic setting, Albanide-Hellenide.

The Albanide-Hellenide ophiolites are remnants of the Middle-Late Jurassic supra-subduction zone (SSZ) oceanic lithosphere that was developed in an intra-oceanic arc setting within the Eastern Mediterranean Tethys. Structural geology and geochemistry of intrusive and extrusive rocks show a peculiar magmatic progression from normal-type MORB (N-MORB) to medium-Ti basalt (MTB), island arc tholeiite (IAT), and boninitic compositions. This magmatic progression shows a broad trend from west to east and throughout time.

The Albanide-Hellenide ophiolites are also characterized by the widespread occurrence of mantle tectonites showing a wide, continuous compositional spectrum ranging from lherzolites to cpx-poor lherzolites, cpx-bearing harzburgites, and cpx-free harzburgites. Many of these rocks show light rare earth elements (LREE) enrichments relative to medium REE (La_N/Sm_N =1.7-4.6), which testify for an LREE-enrichment of previously depleted peridotites by SSZ hydrous fluids.

Therefore, these ophiolites provide us an excellent opportunity for investigating the mutual structural and petrologic relationships between mantle sources, magma generation and mantle residua. To this purpose, REE modelling has been carried out using real mantle peridotites and near-primitive basaltic compositions from a massive dataset collected by the authors in the last decades. Our results indicate that 10-20% partial melting of a depleted MORB-type mantle source generated N-MORB primary magmas, whereas the lherzolites represent the associated residual mantle. Low degree (5-7%) partial melting under high temperature conditions of the MORB residual mantle without addition of SSZ components generated the MTB primary magmas, whereas cpx-poor lherzolites represent the associated mantle residua. 10-20% partial melting of LREE-refertilized MORB residual mantle generated IAT primary magmas and left, as a residuum the harzburgitic mantle. Low degree (~3-8%) partial melting of either LREE-refertilized MTB or IAT residual mantles generated boninitic primary magmas. Alternatively, these magmas may also have been generated from high degree (20-30%) partial melting of LREE-refertilized MORB residual mantle. Cpx-free harzburgites represent the mantle residua associated with boninite formation. Field relations and petrological results indicate a progressive extinction of MORB magmatism and the initiation of arc magmatism in the same tectonic setting. The arc magmatism started with partial melting of MORB residual mantle without addition of SSZ components in an infant forearc setting. Then, it continued through partial melting of progressively depleted mantle sources variably refertilized by SSZ components. The close interconnection between the different mantle peridotites and magma-types indicate that the Albanide-Hellenide ophiolites record a transient phase of plate tectonic reorganisation occurred during the early stages of intra-oceanic subduction.

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Mantle contribution in the oceanic crust

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Keywords: peridotite, troctolite, MORB, melt-rock reaction.

Studies on abyssal gabbros indicate that the lower oceanic crust may form through multistage melt-rock reaction processes between a crystal matrix and melts migrating through it (Lissenberg et al., 2013). This hypothesis implies that melt-rock reactions can be important, if not main, processes governing the petrological evolution of Mid Ocean Ridge Basalts. Recent studies seem to converge on the idea that chemically primitive (olivine-rich) troctolites form through interactions between melts and mantle peridotites at the crust-mantle boundary (e.g., Suhr et al., 2008; Drouin et al., 2010). These rocks received great attention, as their "hybrid" character implies that mantle material can be hidden within the lower crust, arguing against the long-term assumption that the bulk composition of the crust produced at ocean ridges corresponds to that of the melts extracted from the upper mantle (see Sanfilippo et al., 2015). This contribution reviews this idea through a throughout discussion of competing models of formation of olivine-rich troctolites sampled worldwide. The possible role of melt-mantle interaction processes on the composition of the oceanic crust will be then considered on the basis of three study cases. Using thermodynamic calculations, I show that the assimilation of mantle peridotites into a migrating melt may explain the major element composition of the mineral forming a peridotite-troctolite-gabbro sample suite from the Godzilla Megamullion (Philippine sea). Then, I examine the Os isotope composition of a peridotite-troctolite-gabbro association sampled at the Central Indian Ridge, arguing that melt-mantle reactions may produce melts with variable radiogenic Os compositions. Finally, I will use bulk ocean crust estimates of the Hess Deep (Pacific) and Atlantis Massif (Atlantic) ocean crust to quantify a possible effect of hybrid rocks on the bulk crust composition at fast and slow spreading ridges. These studies indicate that interactions at the crust-mantle boundary may contribute to the chemical composition of the bulk oceanic crust, which cannot be considered strictly representative of the melts extracted from the asthenosphere.

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Suhr G., Hellebrand E., Johnson K., Brunelli D., 2008. Stacked gabbro units and intervening mantle: a detailed look at a section of IODP Leg 305, Hole U1309D Geochem. Geophys. Geosyst. 9, doi:10.1029/2008GC002012

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The association of amphibole-bearing mantle peridotites and amphibolitized eclogites of Alpe Morello (Southern Alps)

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Keywords: mantle, amphibole, eclogite.

An hectometre-scale body consisting of amphibole-bearing mantle peridotites and amphibolitized eclogites is exposed at Alpe Morello, along the tectonic boundary separating the Ivrea Verbano Zone from the Strona Ceneri Zone. The peridotite-eclogite association is crosscut pegmatoid dykes having peraluminous granitoid composition and most likely Permian age. The mantle section mainly consists of spinel facies harzburgites and dunites. These peridotites experienced a pervasive hydration event leading to crystallization of tremolite (Al2O3 up to 4 wt%) and chlorite. Tremolite and chlorite are typically associated with olivine, Al-poor orthopyroxene and Cr-rich spinel. The mantle peridotites typically show a tremolite + chlorite foliation that is concordant with the amphibolite facies foliation (hornblende + plagioclase association) of the physically adjacent amphibolitized eclogites. The mantle peridotites include websterite layers and high temperature mylonites characterized by presence of Al-rich amphibole (+ olivine, pyroxene and spinel) and absence of chlorite. Amphibolitized gabbro layers also occur within the mantle peridotites. Furthermore, the mantle peridotites enclose up to 2 cm thick layers made up of tremolite and chlorite, which are most likely related to late transformation of original thin gabbro layers. The amphibolitized eclogites locally preserve evidence for being formed from gabbroic protoliths. The eclogite relics consist of garnet, omphacite and accessory rutile, quartz and kyanite. The eclogites experienced a polyphase decompression evolution that was initially associated with development of Ca-clinopyroxene + plagioclase symplectites after omphacite, Al-rich amphibole + plagioclase kelyphite coronas around garnet, and Al-rich amphibole porphyroblasts. Structural, petrological and geochemical investigations are currently in progress to elucidate whether the studied peridotite-eclogite association: (i) represents an original mantle-gabbro association experiencing on orogenic cycle of subduction and exhumation, or (ii) was produced by tectonic coupling of subducted gabbroic crust with the overlying mantle wedge.

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Melt extraction and enrichment processes in the New Caledonia lherzolites

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Keywords: ophiolite, mantle geochemistry, Sr-Nd isotopes, New Caledonia.

The New Caledonia ophiolite is dominated by mantle lithologies, locally overlain by mafic-ultramafic cumulates derived from boninite-like melts (Secchiari, 2016). The mantle rocks include highly refractory harzburgites and minor lherzolites in both spinel and plagioclase facies. In this study, major, trace elements and Sr-Nd isotopes are used to constrain the mantle evolution of the lherzolites and their relationships with the MORB-type basaltic rocks ("Poya terrane") which tectonically underlie the Peridotite nappe. The lherzolites are low-strain porphyroclastic tectonites. They likely record an asthenospheric origin followed by re-equilibration at lithospheric conditions, as supported by geothermometric estimates for the spinel facies assemblage (T = 1100-940°C). Olivine composition (Fo= 88.5-90.0 mol.%), spinel Cr# ([molar 100 • Cr/(Cr+Al)]= 13-17) and relatively high amounts (7-8 vol.%) of Al_2O_3- and Na_2O-rich clinopyroxene (up to 0.5 and 6.5 wt.%, respectively) indicate a moderately depleted geochemical signature. Bulk rock and clinopyroxene rare earth elements (REE) patterns display a typical abyssal-type signature. REE compositions are consistent with moderate degrees of fractional melting of a DMM source (8-9%), including a first stage of deep melting in the presence of residual garnet. The plagioclase lherzolites show melt impregnation microstructures, Cr- and Ti-rich spinels and incompatible trace element enrichments (REE, Ti, Y, Zr) in bulk rocks and clinopyroxenes. Impregnation modelling for these elements suggests that the plagioclase lherzolites originated from residual spinel lherzolites by entrapment and reaction with highly depleted incremental melt fractions of a MORB-type source in the shallow oceanic lithosphere. Nd isotope compositions of the investigated peridotites are consistent with derivation from an asthenospheric mantle source that experienced a recent MORB-producing depletion event. However, geochemical trace element modelling and Nd isotopes do not support a genetic mantle-crust link between the lherzolites and basaltic rocks from the underlying Poya Terrane. These basalts require the presence of isotopically enriched material, possibly non-peridotitic, in their mantle source. The lherzolite evolution was likely related to seafloor spreading in a marginal basin predating Eocene subduction and formation of the residual harzburgites in a forearc setting. Our study therefore points out the coexistence of peridotites with contrasting geochemical signatures indicative of SSZ- and MOR type melting regimes in the New Caledonia ophiolite.

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SESSION S11

Topography: from the surface to the mantle

CONVENERS AND CHAIRPERSONS

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Spatial patterns in exhumation and surface uplift in the central Pontide mountains during the growth of the northern margin of the Central Anatolian Plateau

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Keywords: orogenic plateau, surface uplift, low-T thermochronology, river channel shortening and thickening.

Located along plate convergent zones, orogenic plateaus are low relief, mostly internally drained and elevated morphotectonic features with steep and highly dissected margins. Although potential physical processes contributing to the formation of plateaus are qualitatively and quantitatively fairly well understood (including both deep-seated and surface processes), available field-based and geophysical data rarely provide firm evidence for the ultimate causes of plateau development.

In this study, we focus on the E-W-striking Central Anatolian Plateau, which is situated between the Arabia-Eurasia collision zone and the upper plate the north-dipping subduction zones of the eastern Mediterranean Sea. This plateau appears to represent a nascent stage of an orogenic plateau. Athough the uplift history of its southern margin has been well documented (0.8 and 1.2 km of surface uplift starting from ~8 to 5.5 Ma and ~1.6 Ma, respectively, possibly in association with deep seated processes; Schildgen et al., 2012), the long-term evolution of the northern plateau margin remains enigmatic.

Our new thermochronologic (apatite fission-track and apatite (U-Th)/He) data from the central Pontide mountains document that after an Eocene stage of tectonic inversion of a deep marine sedimentary basin of Cretaceous to Paleocene age, renewed rock uplift associated with the development of the plateau must have started sometime after 11 Ma (the age of our youngest, partially reset apatite (U-Th)/He sample). Moreover, our analysis of the drainage network reveals that the pattern of surface uplift along the arc-shaped Pontides increases along strike from ~0.3 to 1.1 km. This longitudinal gradient appears to coincide with the modern pattern of shortening rates documented by GPS data. Overall, our data seem to suggest that surface uplift along the northern margin of the CAP should have been controlled by crustal shortening and thickening processes.

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High-resolution seismic survey in the Eastern Sicily offshore: results from the Mt. Etna sector and implications with regional tectonics

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Keywords: Eastern Sicily, Mt. Etna offshore, Active deformation, Seismic reflection.

A grid of high-resolution seismic data has been acquired along the continental shelf/upper slope of the Mt. Etna offshore (eastern Sicily) with the aim to provide new insights on active tectonic structures. Seismo-stratigraphic analysis allowed us to identify four seismic units, bounded by marker reflections, which were correlated with middle-upper Pleistocene sedimentary deposits and volcanic rocks outcropping onland. Tilted and folded Upper Pleistocene deposits suggest that shortening has occurred in the Aci Trezza offshore. Syn-tectonic deposition into a “piggy-back” basin setting (growth folding) is also observed. Asymmetric folding appears to deform the post-20Kyr succession. Tectonic deformation has been related to the migration of ENE-WSW striking reverse faults. Due to their geometry, thrust faults were interpreted as the frontal splays of a fault propagation fold, the offshore extension of the WSW-ENE oriented Catania anticline, an active fold aseismically growing in the northern outskirt of Catania. A long-term convergence rate of at least 1 mm/yr has been estimated by restoring of the 125 ka old reflector; this value is consistent with geodetic regional shortening measured along the front of the Sicilian chain in this area (De Guidi et alii, 2015). North-eastwards, a belt of NW-SE trending extensional faults dislocate a 220-120 ka old volcanic plateau, producing ruptures in the seafloor. These correspond to the seaward extension of the NW-SE trending transtensional Timpe fault system and, similarly to this latter, has favored volcanic intrusions. Seismic data coupled with multibeam data available in literature indicate that the NW-SE trending faults, landward prosecution of the North Alfeo fault system of Gutscher et alii (2015), turn to N-S direction near the Ionian coastline to connect with the Acireale fault, forming, as a whole, a releasing bend zone. Our data suggest that active contractional and extensional tectonic processes coexist in the south-eastern sector of Mt. Etna; thrusting and folding can be related to the late migration of the Sicilian chain front, whereas oblique faulting is probably part of the major kinematic boundary located in the western Ionian Sea. Our data do not show significant deformations related to the southern boundary of the Mt. Etna eastern sliding sector.

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New structural and seismological evidence and interpretation of a lithospheric scale shear zone at the southern edge of the Ionian subduction system (central-eastern Sicily, Italy)

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Keywords: Central Mediterranean, Sicilian/Calabrian subduction system, wrench zone, abandoned STEP fault.

Geological, gravimetric and seismological data from the central-eastern Sicily (Italy) provide evidences of a NW-SE oriented shear zone at the southern edge of the Ionian subduction system. This structure consists of a near 100 km long lithospheric-scale structural and seismic boundary slicing throughout the central-eastern portion of the Sicilian Collision Zone, between the Madonie Mts. range and the Mt. Judica area, SW of Mt. Etna volcano. The associated deformation (e.g. wrenching and time-progressive structural rotations), a substantial topographic imprint in the landscape, its location (laterally to the subducting Ionian crust) and trending (orthogonal to the hinge of the subduction system) support the hypothesis that, during the Pliocene-early Pleistocene (probably), the analyzed boundary served as a STEP fault (sensu Govers and Wortel, 2005) or tearing zone accommodating upper plate deformation along the ancient SW edge of the Ionian Slab. Complete slab detachment beneath NE Sicily (Neri et al., 2009) produced a twofold consequence in the kinematics of the proposed boundary: i) deactivation of the supposed STEP mechanism as a result of subduction cessation in the area and ii) reactivation as a transform belt currently separating the NE side of the boundary, where part of the deformation is accommodated by extension, from a long-standing converging sector, the rest of the Sicily island. Accordingly, the shear zone could currently represents the shallow expression of an incipient transform belt, separating compartments with different motion in the modern context of Africa-Europe convergence and fragmentation. It has probably reactivated a former (Plio-Pleistocene?) STEP segment active before slab detachment within a larger belt within a wide crustal transition zone (Hyblean to Ionian) occurring beneath the NE corner of Sicily. According to several authors (see Gallais et al., 2013; Gutscher et al., 2015; Polonia et al., 2016.; Scarfì et al., 2016), modern STEP faults have developed, following retreating and narrowing of the slab, along other zones of the Calabrian-Ionian subduction system.

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Structural architecture and active deformation pattern in the northern sector of the Aeolian-Tindari-Letojanni fault system (Southern Tyrrhenian Sea - NE Sicily) based on merging of marine and on-land data

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Keywords: Southern Tyrrhenian Sea-NE Sicily, seismic profiles, field data, GPS data, seismological data.

The Aeolian-Tindari-Letojanni fault system (hereinafter ATLFS) is a regional belt of deformation extending from the central sector of the Aeolian Islands to the Ionian coast of Sicily, north of Mt. Etna. Framed in the current geodynamics of the central Mediterranean, this tectonic feature is part of a wider NW-SE oriented right-lateral wrench zone which accommodates diverging motions between the western and eastern sectors of the southern Calabrian Arc edge. Evidences that the ATLFS is still active in its northern sector are provided by seismological, geodetic and geological data. However, several matters about its local scale structural architecture and active deformation pattern are still unsolved and no correlation between seismicity and accountable faults have been satisfactorily produced, particularly in the offshore.

In the frame of the PRIN 2010-2011 project (Active and recent geodynamics of Calabrian Arc and accretionary complex in the Ionian Sea), a merging of marine and on-land structural, seismological and geodetic data was carried out from the Lipari-Vulcano volcanic complex (central sector of the Aeolian Islands) to the on-land sector, along the Peloritani Mountains. The Gulf of Patti, the marine area separating the central Aeolian volcanic islands from north-eastern Sicily, has been investigated through high and very-high resolution seismic reflection and swath bathymetry surveys.

Merging of data suggests that the active deformation pattern of the northern sector of the ATLFS is currently expressed by an én-echelon arranged NW-SE trending right-lateral transtensional fault segments which in the overlap regions form releasing step-over and pull-apart structures. These minor tectonic compartments developed within the larger ATLFS deformation belt and have favoured magma ascent and the shaping of the Lipari-Vulcano volcanic complex. A similar setting is here proposed for the Gulf of Patti that has been interpreted as an extensional relay zone between two overlapping right lateral NW-SE trending bounding faults. As a whole, this faults configuration is well supported by collected seismological and geodetic data which are consistent with kinematics of the detected faults. An interesting aspect is that most of low-magnitude seismicity occurs within the relay zones whilst the largest historical earthquakes (1786, Mw=6.2; 1978, Mw=6.1) seem to have been generated along the overlapping master faults. The results presented here allow not only to advance understanding of the seismotectonics of the ATLFS, but also to test models on its geodynamic significance.

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Petrological and geophysical constraints on density distribution of the Italian crust

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Keywords: dynamic topography, seismic tomography, gravity, thermo-dynamical modeling.

The density distribution of the crust in the Italian peninsula and surrounding regions is fundamental to unravel the dynamic component of topography. Since gravity data suffers from poor resolution and strong equivalence, the best constraint comes from the interpretation of seismic models. The distribution of V_p and V_s velocities has been inferred by seismic tomography and ambient-noise studies. The interpretation of seismic models in terms of temperature, chemical composition and water content is however challenging due to non-uniqueness and non-linear relationships among the involved parameters.

We consider several compositions of the Upper, Middle and Lower Crust from geological records as representative of the Italian geological setting, and predict V_p, V_s, density and their respective ratios by thermo-dynamical modelling. The variability of such quantities due to temperature, composition and water content (set at 0.25 wt%) are evaluated for different depth ranges. Moreover, a comparison with the recent EPCrust (Molinari & Morelli, 2011) and the one from Molinari et al. (2015) is made.

We find that temperature is able to strongly affect V_p and V_s in the entire crust, especially if water is present. For same depth ranges, different compositions give rise to similar values of seismic properties. The variation in density among the Upper, Middle and Lower Crust is relatively higher than that of V_p and V_s, regardless the presence of water. The ratio V_p/V_s significantly changes with chemical composition, showing an overall increase in depth. Poisson's ratio is poorly sensitive to changes in temperature and water content and shows an increase with depth. Finally, the ratio V_s/density appears to be rather constant regardless the water content, temperature and composition. EPCrust and the model from Molinari & Boschi (2015) show comparable variations of V_p, V_s and density within the different crustal layers. Nonetheless, the different assumptions and data implemented in the models result into differences that are important for interpretation in terms of physical properties. Our results provide physical constraints for the joint-inversion of geophysical datasets (i.e. seismic and gravity observations), therefore narrowing the range of models fitting the experimental data. Moreover, our observations can improve the interpretation of seismic anomalies and the related implications in geodynamics.

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Erosion rates across space and time from a multi-proxy study of rivers of eastern Taiwan

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Keywords: Taiwan, erosion rate, topogragy, multi-proxy.

Taiwan is a young arc-continent collisional orogen with high seismicity, rapid rates of exhumation, high relief and subtropical climate condition with very high precipiation. Its tectonic setting with an obliquity between the convergence direction and the trend of the plate boundary, and its switch in subduction polarity provides a gradient in uplift and variations in longevity of orogeny with a young, immature orogen in the south, mature orogeny in central and northern Taiwan, and perhaps even the cessation of orogeny in the far north. To investigate how tectonic gradients are expressed in the spatial and temporal patterns of erosion rate, we apply detrital zircon fission track and cosmogenic nuclide dating to sediment from the modern rivers of eastern Taiwan, where rocks are exhumed at the highest rates and from the greatest depths. We compare erosion rates derived from these proxies with modern precipitation, large scale geomorphic characterists and suspended sediment loads.

The modern zircon fission track detrital record is consistent with basement ages that show that much of the orogen is eroding at high rates with basin-wide mean zircon FT cooling ages as young as 0.9 Ma. The concentrations of cosmogenic nuclides (^{10}Be) are extremely low but significantly above background levels. The erosion rates derived from both ^{10}Be concentrations and FT cooling ages are remarkable similar in magnitude and spatial pattern in spite of the fact that the methods integrate over different timescales, ranging from millenial (^{10}Be) to millions of years (FT). Erosion rates are lowest in the incipient collision of zone of southern Taiwan (< 1 km/Ma) in southern Taiwan, and increase to values ≥ 4 km/Ma in central Taiwan. They subsequently decrease again in the far north, where it has been argued that convergent orogeny has ended. These rate estimates are lower than those derived from decadal river sediment load data, which also show greater variability. Mid- and long-term erosion rates, river steepness, mean and maximum elevation are all spatially correlated but we find no systematic relationship with modern precipitation, although north-south variations in precipitation are not large. These observations suggest that the primary control on topography and erosion rates at the long- and mid-term time scale is the teconic configuration of the orogen and that geomorphic processes at the longest wavelegths are stationary over the timescale of thousands to one million years. In contrast, fluvial processes and landslides driven by channel-lowering and extreme climate events and earthquakes affect the sediment yeld at the decadal timescale.

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Mantle dynamics in the Red Sea region

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Keywords: Dynamic topography, Geodynamics, Mantle flow, Mantle convection, Red Sea.

Understanding geodynamic processes associated with the transition from continental rifting to sea floor spreading is a major challenge in the Earth Sciences since they are still poorly known. The Red Sea is the unique place in the world where these processes can be studied, because it shows all the different opening stages of formation of a new ocean. The opening of the Red Sea started 30 Myrs ago as a conseguence of slab pull exerted along the southern Eurasian subduction zone. At the same time the impingement of the Afar mantle plume started to uplift the Ethiopian plateau and the southwestern margin of Arabia. This uplift has been explained in terms of dynamic topography, that is, topography variations caused by vertical components of mantle flow (Moucha & Forte, 2011).

We studied the evolution of the mantle flow beneath the Red Sea region since 30 Ma determining velocity fields in the upper mantle, as well as temperature and pressure fields at assigned time steps and depths. The boundary and initial conditions were assigned incorporating plate kinematics and taking into account of lateral variations of lithosphere thickness. The mantle was assumed to be formed by three layers with different viscosity plus two thermal boundary layers at the top and the bottom. To this purpose, we compiled a map of the lithosphere – asthenosphere boundary for the Red Sea region on the basis of published data. The dynamic model was tested using ASPECT (version1.5.0-pre), a multiprocessor finite elements numerical modelling software designed to solve mantle convection problems on the basis of conservation laws of mass, momentum, and energy, and the state equation. This code was run on a parallel cluster of 64 CPUs available in the geophysics lab of the University of Camerino to obtain adequate performance.

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Drainage network evolution and landscape response to active tectonics in the Bradanic trough, Southern Italy

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Keywords: Bradanic trough, drainage network, landscape evolution, quantitative geomorphology.

The Bradanic trough represents the foredeep between the Southern Apennine and the Apulian foreland and was filled between the Pliocene and the Pleistocene by a 3-4 km thick sequence of deep-to-shallow marine sediments. The present-day topography of the Bradanic trough is eroded by rivers draining into the Adriatic and Ionian Sea and developed in the upper 600 m of the sedimentary succession, indicating that uplift of the basin occurred during the Quaternary. Along the Adriatic and Ionian coast, suites of marine terraces record the pattern of the regional uplift.

In this study we show that the landscape of the Bradanic foredeep results from successive steps of drainage network reorgnization. We analyzed transformed river profiles (Perron & Royden, 2013) extracted from digital topographic datasets and used a quantitative methodology to measure the stability of drainage divides (Willett et al., 2014). The results of our morphometric analysis suggests that the rivers draining the Bradanic trough are still adjusting in response to the regional uplift by lateral migration of drainage divides and cannibalization of neighbouring basins. Our analysis reveals past and pending river captures and shows that local tectonics associated with the activity of the Pleistocene Monte Vulture volcano influenced the landscape evolution in the northern part of the Bradanic trough. Our study provides insights to understand the history of uplift and the interactions between surface and deep processes.

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Lithologic control on exhumation and topographic growth: insights from detrital thermochronology and cosmogenic analyses in the Northern Apennines and the Western Alps

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Keywords: Fission tracks, cosmogenic nuclides, exhumation, topography, Alps, Apennines.

The lithologic control on topographic growth during rock uplift and exhumation is still poorly explored. Here, we tackle this issue by comparing the detrital apatite fission-track (AFT) and cosmogenic data in two key areas of the Alps-Apennines system, i.e., the northern Western Alps and the northermost segment of the Apenninic belt. Both areas are characterized by an apparent transpressional framework during the last stages of rock uplift and exhumation but, despite the similar tectonic framework, they display contrasting characters both in terms of lithology and topographic relief.

In the low-relief Northern Apennines, AFT analysis on modern river sands yielded prominent AFT age populations younger than the stratigraphic age of eroded bedrock (Malusà & Balestrieri, 2012). This indicates that outcropping rocks experienced at least 3-4 km of post-depositional burial, largely due to the overburden of thick Epiligurian successions now almost completely eroded. The early Pliocene age of the youngest grain-age populations reflects the timing of surface uplift and onset of erosional exhumation in this sector of the belt. Average exhumation rates were on the order of 1 km/Ma, and decreased towards the Po Plain where post-Burdigalian wedge-top successions are still preserved. Fast erosion is still active today, as attested by ^{10}Be-derived denudation rates on the order of 0.4-0.5 mm/a (Wittmann et al., submitted).

In the high-relief Western Alps, major fault-bounded blocks display distinct and not overlapping bedrock AFT ages. This age structure allowed us to constrain the erosion pattern both on long-term and short-term timescales, by performing sediment budgets based on detrital AFT analysis on modern river sands (Malusà et al., 2016). Results highlight a short-term erosion pattern with bedload erosion rates on the order of 0.4-0.5 mm/a in the External Massifs (showing bedrock AFT ages of 6-7 Ma), and ~0.1 mm/a in the axial metamorphic units. Such erosion pattern is consistent with ^{10}Be-derived denudation rates measured in the same samples (Wittmann et al., submitted), and reveals a progressive westward shift of erosional foci through time.

Long-term and short-term erosion rates during rock uplift in the External Massifs and Northern Apennines are quite similar, despite of the contrasting topography. The smoothness of the Northern Apennines topography can thus be explained by the higher erodibility of its rocks in comparison to the granitoid rocks composing the External Massifs. This suggests that lithology may determine an upper threshold to topography development, and a delayed response of erosional exhumation to rock uplift.

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Geophysical and geotechnical observations to assess the morphological risk in the acque albule basin sinkhole prone area (Rome, Italy): two case studies

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Keywords: Acque Albule Basin, risk assessment, sinkhole.

We present the results of multidisciplinary investigations of two significant sites, located in the Acque Albule Basin (AAB), 25 km Northeast of Rome (Italy). This basin has been interpreted as a transtensional structure, lying in the western margin of the Apennine range and affecting the Plio-Pleistocene sedimentary and volcanic sequences. During late Pleistocene times, AAB has been filled in with thermogenic travertine of variable thickness. Since historical time, lithoid travertine has been quarried, becoming the main building material during the Roman period (Lapis Tiburtinus). At present, the mining activity still represents the main economic resource of the region together with thermal baths. After the end of the II World War this area has experienced a strong urbanization and marshy lands were transformed into densely populated areas affected by subsidence and sinkhole phenomena. In order to characterize these environmental hazards from the geophysical and geotechnical point of view, we chose two test sites close to relevant anthropic infrastructures. Site A, located at the southern side of the Guidonia military airport and beside an important road; site B, a few kilometers South-East of site A, lies next to the Regina and Colonnelle Lakes and close to the Roma-Pescara railway. The former feature is a large sinkhole depression, hundreds of meters in width, characterized by ongoing subsidence, whereas the latter consists of two sinkholes actually acting as springs. Both sites lie in proximity of inferred faults, which would affect the AAB in the N-S and NE-SW– directions respectively.

The aim of this study is to compare the two cases by collecting geological, geomorphological and geophysical parameters and thus testing the variable controlling their formation and development. We also extended the geophysical campaign in the surrounding area using a multidisciplinary approach to image both surface and subsurface features. We carried out stratigraphic and geomorphological survey, 2 and 3D Geoelectrical Tomography (ERT), differential GPS altimetry, gravity, magnetic, seismic, and soil gas measurements. Moreover, two drillings have been bored inside and outside the depression area of the Site A, reaching depths of 60 and 20 meter, respectively. Geotechnical parameters of the recovered stratigraphy were also measured by laboratory tests.

In general, the approach we propose could provide key elements to recognize similar situations in sinkhole prone areas. Moreover, comparative analysis together with the monitoring of the A site can represent useful tools to understand the genesis and dynamics of phenomena and hopefully to forecast their evolution, particularly in the parts of the basin where active movements caused fractures and damages to buildings and infrastructures.

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Interaction of active crustal deformation, historical seismicity and regional uplift in the upper plate of subduction zones constrained by investigating tectonically-deformed Late Quaternary palaeoshorelines using synchronous correlation: Vibo Fault and Capo D'Orlando Fault, southern Italy.

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Keywords: Quaternary palaoeshorelines, uplift, synchronous correlations method, uplift rate, normal faultin

Crustal deformation within the overriding plate of the Calabrian subduction zone has been investigated by mapping and modelling sequences of Late Quaternary marine terraces tectonically-deformed by active normal faulting. In particular, we attempt to constrain the relationship between regional uplift, upper plate crustal extensional processes and historical seismicity. Crustal deformation can be calculated over multiple seismic cycles by mapping Quaternary tectonically-deformed palaeoshorelines, both in the hangingwall and footwall of active normal faults. The investigated faults, the Vibo Fault and the Capo D'Orlando Fault, lie within the deforming Calabrian Arc which has experienced damaging seismic events such as the 1908 Messina Strait earthquake (~ Mw 7) and other damaging events close to Capo Vaticano pensinsula in 1905 A.D. (~ Mw 7). Other events near Capo D'Orlando town are known from 1613 and 1739 A.D. (~ Mw 5.6-5.1), yet the Capo D'Orlando fault is considered by some not to be a potential seismogenic source. These normal faults uplift and deform Quaternary palaeoshorelines, which outcrop in their hangingwalls, implying that a background regional uplift outpaces fault-related subsidence. The regional uplift signal is likley due to the long-term slip-distribution from the subduction interface; for this reason, we attempt to constrain rates of normal fault deformation so it can be removed from the subduction signal. To do this we use a synchronous correlation method between multiple palaeoshoreline elevations and multiple ages of sea-level highstands which takes advantage of the fact that (i) sea-level highstands are not evenly-spaced in time, yet must correlate with palaeoshorelines that are commonly not evenly-spaced in elevation, and (ii) that older terraces may be destroyed and/or overprinted by younger highstands, so that the next higher or lower palaeoshoreline does not necessarily correlate with the next older or younger sea-level highstand. Our new GIS-based and field-based mapping and published mapping show that palaeoshoreline elevations change along the strike of the investigated normal faults in their hangingwall. This along-strike change in uplift/subsidence is caused by the along-strike fault displacement gradient; the fact that the hangingwall terraces have been preserved is indicative of subduction-related uplift outpacing subsidence caused by normal faulting. Our synchronous correlation modelling assigns new ages to the palaeoshorelines driven by new age controls and published ages allowing us to calculate new uplift rates and rates of vertical fault slip. Long term constant uplift rates through time increase from centre of the hangingwall to beyond the fault tips by a factor of ~ 2 and ~ 4 respectively for the Capo D'Orlando Fault and the Vibo Fault suggesting that they are active and partially accommodating the regional extension affecting the overriding plate. Mapped Late Quaternary marine deposits on their footwalls allow us to derive long-term constant slip rates of 1mm/yr on the Vibo Fault and 0.61mm/yr on the Capo D'Orlando Fault if the footwall uplift to hangingwall subsidence ratio is within a range of 1:4 and 1:3.5 respectively. These slip-rates are comparable to those for other known active normal faults in the Italian Peninsula, implying significant seismic hazard. Upper plate extension and related vertical motions complicate the process of deriving information on the subduction process, such as coupling and slip distribution on the subduction interface, parameters that are commonly inferred for other subduction zones without considering upper plate deformation.

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Cenozoic rejuvenation events of massif central topography (France): insights from cosmogenic denudation rates, river profiles and low-t thermochronology

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Keywords: Cosmogenic denudation rates, thermochronology, French Central Massif, topography rejuvenation.

Located in the foreland domain of both the Alpine and Pyrenean mountain belt, the French Massif Central is a portion of the Hercynian belt that represents an intriguing topographic features: in fact the present topography of the French Massif Central is remarkably higher than other Hercynian belt remnants in Europe. While the crustal deformation is mainly Hercynian in age, during the Mesozoic to Cenozoic the French Massif Central was involved only marginally in the main tectonic events which deeply modify the topography of the Africa-Europe plate boundary. For this reason the French Massif Central is a key site to study short- and long- term topographic response in a framework of slow tectonic activity. In particular the origin of the Massif Central topography is a topical issue still debated, where the role of mantle upwelling is invoked by different authors.

Here we present a landscape evolution analysis by means the denudation rate derived by basin-averaged cosmogenic concentration coupled with river longitudinal profiles and low-temperature thermochronology. This analysis allow us to recognize that French Massif Central topography undergoes to transient state conditions.

Our data put attention to the tricky coexistence of the out-of-equilibrium river profiles, incised valleys, and low denudation rates that range between 40 mm/kyr to 80 mm/kyr. Overall the (U-Th)/He analysis displays evidence that the majority of the sample cooled through the partial retention zone (~65° C) during a time spanning between Lower Cretaceous and Eocene time.

The spatial distribution of denudation rates and thermochronological data coupled with topography analysis enabled us to trace the signal of the long-term uplift history, to propose a chronology for the uplift evolution and a possible cause of the present topography of the Massif Central.

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Surficial response to the Late Quaternary tectonic deformation: new morphometric insights from relief analysis of NE Sicily (southern Italy)

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Keywords: Relief, Morphological response, NE Sicily, Calabrian Arc.

Tectonic forcing causes the relief building of mountain chains and enforces the surficial processes in a persistent dismantling of rock volumes, continuously modelling earth morphology. Actually, we observe transient landscapes that have temporarily recorded tectonic forcing as a codified signal. The Late Quaternary tectonic evolution of the northeastern Sicily, located along the Africa-Europe plate boundary (Serpelloni et al., 2007), at the southern termination of the Calabrian arc, has been dominated by intense dynamics (Lentini et al., 1995; Pavano et al., 2015) that severely modified the Late Miocene landscape. Basing on geological dataset, the reconstruction of the Plio-Pleistocene tectonic evolution of the region, give us the opportunity to test a methodology for investigating the pathway of the morphological response to deformation. Our study consists of the restitution on maps of the values of the common morphometric indexes measured for each cell of grids. The analyses of the results, framed in a general interpretation of the age of the relief cumulated in the region, evidence that the Topographic Relief map and the Elevation Relief Ratio (Pike & Wilson, 1971) are good indicators, for detecting the different evolutionary stage of the local topography, with a resolution depending on the size of the adopted grid. We find evidences of differential morphological responses within distinct sectors of the studied region, useful to define a general time-relating pathway of the main landscape metrics.

We tested the powerful of this methodology in identifying the location of the inner-edge of the main raised hilltop surfaces, marking the different stages of the tectonic uplifting of the region. Our method could have wider application in preliminary investigations of the landscape of large regions, useful to address more focused morphological analyses.

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Knickpoints as geologic markers of rock uplift and long-term erosion

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Keywords: knickpoints, knickpoint modeling, long-term erosion rate, NE Sicily, Peloritani Mountains.

Unsteady base level fall at the mouths of rivers, such as those that flow directly into the sea, generates knickpoints that migrate upstream as a transient through the drainage network. These knickpoints will climb vertically at the same rate as long as their migration follows a detachment limited stream power law, where the power dependency of the slope term is ~1 and the drainage area is fixed (Howard, 1994). By modelling their age, knickpoints could represent useful geomorphic markers, much in the same way that river terraces are used, to document unsteady and non-uniform fluvial incision in response to active tectonics. Here, the results demonstrate knickpoints as geomorphic markers in the streams draining the Ionian flank of the Peloritani Mountains in NE Sicily. The Peloritani Mountains lie in the footwall of an ~40 km long, offshore, NE-SW oriented normal fault, belonging to a broader belt of extension stretching from southeastern Sicily north into western Calabria. Footwall uplift is documented by a flight of Late Quaternary marine terraces (Catalano and De Guidi, 2003). Using slope-area analysis on the major east-flowing streams, we find that the tops of many prominent knickpoints project down to the coast where they intersect the marine terraces, thus providing an age for that specific knickpoint and the paleo-long profile. We model the migration rate of those dated knickpoints to locally solve for the parameters in the detachment limited stream power law (Berlin and Anderson, 2007), and apply the results to model the age of other knickpoints with no clear connection to marine terraces.

In summary, we find that the eastern Peloritani Mountains have been uplifted in an along-strike elliptical pattern, consistent with the general deformation model for the footwall of a normal fault. Moreover, a calculation of the eroded rock volume beneath the dated paleo-long profiles reveals a tight, positive, non-linear relationship between the long-term erosion rate and the modelled, normalized channel steepness (k_{sn}) (DiBiase et al., 2010).

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Topography: from the surface to the mantle in eastern North America (ENAM), a seismically active and deforming plate interior

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Keywords: intraplate seismicity tectonic geomorphology geodynamic modeling.

Unlike plate boundaries, plate interiors lack a systems-level model that integrates the geologic, geodynamic, seismologic, and geomorphologic processes that collectively shape topography. Eastern North America (ENAM) lies in a plate interior where recent seismologic and geomorphic experiments, along with studies of a modest-sized earthquake, are being synthesized into a novel geodynamic model that explains the stress field and makes testable predictions of crustal deformation. Here there is a history of large (M 7), infrequent, and clustered earthquakes. In the context of this seismicity, paleogeodetic geomorphic markers and topographic metrics provide a rare opportunity to quantify the crustal deformation rate and test it against model predictions. The epicenter region of the 2011 M 5.8 Mineral, Virginia earthquake, an event that shares much in common with the 2012 Mirandola earthquake, is traversed by the South Anna River. A stratigraphic model of river terraces using OSL, IRSL, and TCN geochronology demonstrates that the long term incision rate in the uplifting hanging wall of the fault is approximately double the incision rate in the subsiding footwall. The terraces are arched up and over the surface projection of the fault plane that has been modeled to have generated ~7 cm of surface deformation distributed over a wavelength consistent with the deformed terraces. Spectral analysis of river channel planimetric form here and more broadly in ENAM indicate that the sinuosity of seismic zones is distinct from aseismic areas, providing a paleogeodetic metric sensitive to subtle crustal deformation. With ideas ranging from glacial isostatic adjustment (GIA), to ridge-push effects, to lithospheric foundering, and sub-lithospheric mantle convection there is little consensus on the more regional geodynamic processes that build the crustal stresses leading to these earthquakes and surface deformation. Here, we present a self-consistent global model of the dynamics of ENAM that takes the first step in explaining the ENAM stress field. The model includes the effects of topography, lithospheric structure including crustal thickness, and coupling with density-buoyancy driven mantle flow. A new crustal thickness map, generated by strong P to S conversions from 103 USArray TA and permanent stations, shows a steep gradient beneath the Appalachian Piedmont, largely coincident with seismicity, where the crust thickens from ~30 to 40 km. The model is particularly sensitive to these changes in lithospheric structure and suggests that ENAM seismicity and crustal deformation arises from a combination of lithosphere topography and structure, coupled with the effects of density-driven mantle flow. Maximum predicted shortening rates approaching ~0.5 mm/yr across the Piedmont and Coastal Plane regions underscore the real, but poorly understood seismic hazards that can exist for plate interiors like ENAM.

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Slab segmentation vs. Apennines segmentation: insights from Receiver Function analysis

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Keywords: Slab segmentation, Apennines orogen, Receiver function.

The birth and development of the Apennines orogen seem to be tightly related to the sinking of the Ionian oceanic plate in the upper mantle and the eastward retreat of the subduction trench. At a regional scale, the Apennines orogen can be broadly subdivided in four domains: Northern, Central and Southern Apennines, and the Calabrian arc. The different characteristics of these domains could be related to different mountain building processes due to the segmentation of the subduction system. In fact, during the retreat of the Ionian plate the passive continental margins entered the subduction system as a consequence of the narrow width of the oceanic plate. Episodes of continental subduction generated strong heterogeneity in the buoyancy of the subducted materials. Moreover, the length of the subduction trench almost triplicated in the last 10 Million years. Both these points suggested the possibility of a segmentation of the subduction system (e.g. Lucente and Speranza, 2001; Rosenbaum et al., 2008). Slab segmentation has been also invoked for explaining the Bouguer gravity anomaly over peninsular Italy and the distribution of foredeep basins (Royden et al., 1987). Seismic tomography confirmed the presence of discontinuous high P-wave velocity body within the upper mantle beneath the Apennines, interpreted as segments of a cold subducted slab (Piromallo and Morelli, 2003; Giacomuzzi et al., 2011). At present, it is widely accepted that the Apennines subduction is still on-going beneath the Calabrian arc, where deep-focus seismic events occur, and beneath the Northern Apennines, where intermediate-depth events have been also located. The contrasting nature of these two subduction zones has been pointed out in many studies (Carminati et al., 2005). In this contribution, I report the evidence of the Apennines slab segmentation as seen by P- and S- receiver function, showing that slab segmentation broadly correlates to along-strike discontinuities of the Apennines orogen. At large scale, the analysis of S-receiver function (SRF) along the peninsula clearly highlighted the presence of heterogeneity in the lithosphere-asthenosphere boundary (LAB) depth, and in its velocity gradient, beneath Southern Apennines, in agreement with the hypothesized slab window in the area (Miller and Piana Agostinetti, 2012). S-RF also point out the presence of a sharp change in the nature of the velocity jump at the LAB under the Central Apennines, suggesting a dramatic change in the properties of the asthenopheric materials beneath this portion of the Apennines, possibly related to the presence of fluids derived form the metamorphism of the subducted materials. P-receiver function (PRF) can reach higher resolution with respect of SRF and they have been used to directly image the area where the slab segmentation occurs. Due to the differences in the nature of the subducted materials, the age of the slab vertical tearing and the subduction process (e.g. the retreat velocity of the subduction trench), slab segmentation displays different characteristics along peninsular Italy. In the Northern Apennines, slab segmentation appears as an incipient vertical tear in the slab, off-setting the subducted body by no more than 30 km along the normal to the Apennines strike (Rosenbaum and Piana Agostinetti, 2015). At the junction between the Southern Apennines and the Calabrian arc, a more mature vertical slab tear is imaged, where both the Moho and the LAB display along-strike discontinuities. However, no toroidal flow in the upper mantle has been found there, suggesting that the two edges of the slab are still in contact (Chiarabba et al., 2016). In the Messina strait, where the tearing process has been complete, with the development of full toroidal flow in the upper mantle, the tearing process has been recorded in the fabrics of the crustal materials on the two side of the strait.

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The multi-phased uplift of the Central Anatolian plateau southern margin: evidence from stratigraphy and implications for the geodynamic model

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Keywords: plateau uplift, multi-phased uplift, Mut Basin, Adana Basin, Central Anatolian Plateau, southern Turkey.

The Cenozoic Mut and Adana basins, lying respectively on top and at the foot of the southern margin of the Central Anatolian Plateau (CAP, southern Turkey), are strategically located to record topographic and tectonic changes in the easternmost Mediterranean realm. Deposits infilling the Mut and Adana basins record marine sedimentation persisting in both the basins up to early Messinian, implying that the southern margin of the CAP, today hosting the Mut Basin, was not yet uplifted at that time. We show that two distinct uplift phases concurred to bring the southern margin of the CAP to its present-day average elevation of ca. 2 km a.s.l. The younger uplift phase has started during Middle Pleistocene and has produced ca. 1.5 km of uplift, as indicated by both i) the presence, in the Mut Basin, of Plio-Pleistocene marine sediments today mapped at elevations up to 1.55 km a.s.l and ii) biostratigraphical investigations carried on Plio-Pleistocene samples indicating paleodepths of ca. 0.5-0.7 km b.s.l. for sediments today lying at an elevation of ca. 1.0 km a.s.l.. The Middle Pleistocene uplift phase was preceded by an earlier, late Messinian phase implying ca. 0.5 km of uplift. This earlier uplift event is time-constrained between ca. 5.45 Ma, when a large influx of sedimentary material started to be delivered to the Adana Basin from the CAP southern margin, and 5.33 Ma, the age of the restoration of deep marine depositional conditions in the Adana Basin. Interestingly, even if partly coeval with the first uplift phase of the CAP southern margin, the Messinian Salinity Crisis – an extreme event which implied a major drawdown of the Mediterranean sea level – cannot be solely accounted for the changes recorded in the Adana Basin. Re-establishment of marine conditions after a chronostratigraphic gap is documented also in the Mut Basin, with the deposition of a Plio-Pleistocene succession unconformably lying above a Miocene succession. Bio-chronostratigraphic investigations carried on this younger marine sequence allowed us to constrain the maximum age of the younger uplift phase to 0.52 Ma.

The precise constraints we obtained on the timing and amount of uplift of both the two recognized uplift phases allowed us to estimate uplift-rate values of > 4 mm/yr for the earlier phase and ca. 2.9 mm/yr for the younger phase. These extremely high uplift rates imply a deep-seated mechanism as the cause of the CAP southern margin uplift. Moreover, our results requires a geodynamic model integrating a deep-seated mechanism capable of generating distinct and limited-in-time uplift phases characterized by very high uplift rates and separated by episodes of stasis in the uplift, or even subsidence.

Viscous roots of active seismogenic faults revealed by geologic slip rate variations, central Italy

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Keywords: Brittle faults, viscous shear zones, topographic stresses.

Some extensional regions are associated with high topography containing parallel sets of active normal faults. However, it is unclear how these parallel faults interact over multiple seismic cycles. We know that brittle/elastic seismogenic normal faults at the surface are underlain by more viscous deformation at depth. Here we suggest that during the earthquake cycle viscous flow at depth may drive elastic strain accumulation along seismogenic faults and that strain-rates across the faults, when summed across strike, allow us to understand the stresses driving the deformation and how parallel sets of faults interact. It has been difficult to understand the contribution to fault loading from viscous flow at depth because it has been unclear whether viscous deformation mainly occurs in shear zones or by distributed flow. Also, viscous strain rate has a power-law dependence on applied stress, but up-scaled measurements from laboratory experiments have been our only estimate of the power-law exponent applicable to the much longer term in situ behaviour of active faults. Here we show that measurements of topography and whole-Holocene offsets averaged across the strike of parallel sets of seismically active normal faults in the Italian Apennines can be used to derive a relationship between stress and strain rate averaged over 15±3 kyrs. This region overlies a slab window, and has high topography, which has been suggested to be dynamically-supported by mantle flow. The derived relationship between stress and strain rate, follows a well-defined power-law with an exponent in the range 3.0-3.3. This information, when combined with heat-flow measurements and flow-laws from laboratory experiments, can be used to infer the rheological structure of the crust and constrain the width of active shear zones beneath the Apennines. Note that the power-law relationship with an exponent of 3.0-3.3 is derived from measurements of strain-rate on brittle faults. Clearly this is unexpected as power-law behaviour is associated with viscous deformation, not brittle deformation. We reconcile this by suggesting that that the irregular, stick-slip movement of upper crustal brittle faults, and hence earthquake recurrence, are controlled by down-dip viscous flow in shear zones over multiple earthquake cycles. This confirms the long-held view that brittle faults root into viscous shear zones. It also suggests that stresses associated with topography, which develop as a result of dynamic support from the mantle, drive deformation rates that control the multi-seismic-cycle rate of earthquake occurrence.

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Long-term, deep-mantle support of the Ethiopia-Yemen Plateau

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Keywords: Dynamic topography, Ethiopian Plateau, Large igneous province, Flexural uplift, Topography evolution.

Ethiopia is a key site to investigate the interactions between mantle dynamics and surface processes because of the presence of the Main Ethiopian Rift (MER), Cenozoic continental flood basalt volcanism, and plateau uplift. The role of mantle plumes in causing Ethiopia's flood basalts and tectonics has been commonly accepted. However, the location and number of plumes and their impact on surface uplift are still uncertain. Here, we present new constraints on the geological and topographic evolution of the Ethiopian Plateau (NW Ethiopia) prior to and after the emplacement of the large flood basalts (40-20 Ma). Using geological information and topographic reconstructions, we show that the large topographic dome that we see today is a long-term feature, already present prior the emplacement of the flood basalts. We also infer that large-scale doming operated even after the emplacement of the flood basalts. Using a comparison with the present-day topographic setting we show that an important component of the topography has been and is presently represented by a residual, non-isostatic, dynamic contribution. We conclude that the growth of the Ethiopian Plateau is a long-term, probably still active, dynamically supported process. Our arguments provide constraints on the processes leading to the formation of one of the largest igneous plateaus on Earth.

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Evolution of continental-scale drainage in response to mantle dynamics and surface processes: an example from the Ethiopian Highlands

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Keywords: Ethiopian Highlands topography, River network, Knickpoint celerity model, Landscape evolution.

Ethiopia offers an excellent opportunity to study the effects and linkage between mantle dynamics and surface processes on landscape evolution. The Ethiopian Highlands (NW Ethiopia), characterized by a huge basaltic plateau, is part of the African Superswell, a wide region of dynamically-supported anomalously high topography related to the rising of the Afar plume. The initiation and steadiness of dynamic support beneath Ethiopia has been explored in several studies. However the presence, role, and timing of dynamic support beneath Ethiopia and its relationship with continental flood basalts volcanism and surface processes are poorly defined. Here, we present a geomorphological analysis of the Ethiopian Highlands supplying new constrains on the evolution of river network. We investigated the general topographic features (filtered topography, swath profiles, local relief) and the river network (river longitudinal profiles) of the study area. We also apply a knickpoint celerity model in order to provide a chronological framework to the evolution of the river network. The results trace the long-term progressive capture of the Ethiopian Highlands drainage system and confirm the long-term dynamic support of the area, documenting its impact on the contrasting development of the Blue Nile and Tekeze basins.

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Surface and deep deformation of the great Alpine region from GPS and seismic anisotropy measurements

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Keywords: Alps, geodynamics, geodesy, kinematics, crustal deformation, mantle deformation.

The comparison of crustal and mantle shear directions can provide insights into the extent of crustal-mantle coupling and the dynamics guiding surface kinematics and active tectonics in continental deformation zones. The recent developments of the European GNSS infrastructure allow to precisely determining crustal deformation over the Alps. Unlike the crust, the orientation of the strain field within the mantle cannot be directly measured and must be inferred from either mantle earthquakes or seismic observations, such as seismic anisotropy observations. In this work we analyze crustal stress and strain rates, from seismic and GPS data, and mantle deformation, inferred from SKS shear wave splitting measurements, in the great Alpine region (GAR). We compiled a new map of SKS directions merging data collected during several experiments and available from different databases, deriving a new continuous mantle deformation pattern over the GAR. The crustal deformation pattern is derived from a dataset of ~600 surface velocities obtained from the analysis of continuous GPS stations. Since geodetically determined displacements of the Earth's surface reflect the response to different processes acting at different spatial scales, in the comparison between crustal and mantle deformation we accounted for the intrinsic multi-scale characteristics of geodetic deformation measurements. We estimate the geodetic strain-rate field using a multi-scale spherical wavelet-based method, where the velocity value at a given point of the Earth's surface is obtained as a superposition of values obtained at different spatial scales. We considered the vertical component of the GPS velocities, finding that the spatial gradients of the vertical velocity field do not constitute a significant part of the deformation over the Alps. From the geodetic strain-rate tensors we computed the two planes of shear (or no-length-changes, NLC) directions, which are compared with the directions of SKS splitting. We exploit the multi-scale approach by comparing the SKS directions with geodetic shear directions computed starting from strain-rate fields estimated considering different spatial lengths. The geodetic NLC directions computed from strain-rates estimated by filtering out the shorter wavelengths tectonic signals better match the mantle anisotropy directions. We found that in all cases (i.e. for all of the wavelets orders considered in the multi-scale geodetic strain-rate analysis) the dextral NLC orientations better match the orientations of mantle seismic anisotropy, in agreement with the general eastward motion and right-lateral kinematics of the Alpine belt. Overall, we found a good agreement between geodetic and seismic observations in the eastern Alps and a poorer agreement in the western Alps. In this contribution the interconnections between crust and mantle strains are showed and the geodynamic implications are discussed.

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Preliminary results on the uplift of the Eastern Cordillera, Colombia

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Keywords: topography, thermochronology, flat slab, fluvial piracy, Eastern Cordillera, Colombia.

The Eastern Cordillera (EC) of Colombia is a double vergent thrust and fold belt formed in Cenozoic time by the inversion of a Mesozoic rift. The chain is active in the eastern front while the western flank appears to be abandoned. Tomography and seismicity highlight that the widest segment of the EC is related to the presence of a flat slab producing shortening in the overriding plate. Our goal is to explore the relation between surface, crustal and deep processes in the topography growth of the EC north of 6° N. To reach this aim we integrate data derived from the fluvial network analysis with long-term erosion data derived from thermochronology.

The northern EC is an asymmetric chain with a gentle flank on the western side and steep flank to the east. The two sides are separated by the maximum elevation of 5000 m reached at the Cocuy Sierra. Here the EC has the widest length and changes northward to the Santander Massif Range. Along strike, the topography is symmetric with decreasing elevation moving north- and south-ward from the Cocuy peak. The main rivers draining the EC flow parallel to the main structures and locally cut across them. We obtained new low-T thermochronometric (U-Th/He) ages on zircons (ZHe) and apatites (AHe) from samples collected along two transects. Our ages combined with previous data (Caballero *et al*., 2013; Mora et al*.,* 2015) indicate that along both transects exhumation occurred from very shallow burial depths (≤ 6-8 km) during the Oligo-Miocene and locally continued until the Pliocene. Along the transect across the central part of the EC up to the Cocuy Sierra, the youngest Pliocene ages (AHe) are located at the highest elevations above 4000 m. Along the second transect the youngest ages are found close to and east of a main strike-slip structure (Bucaramanga fault). This fault has a quite significant dip-slip component evidenced by an offset of about 10 Ma among the AHe ages across the fault. Wind gaps and river elbows suggest an ongoing drainage reorganization by fluvial piracy. The analysis of the river longitudinal profiles, the distribution of Pleistocene fluvial deposits, the chi-plots and widespread mass wasting processes indicate a landscape in disequilibrium.

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Tectonics and topography of the Moroccan Atlas I: 250 My history of subsidence of uplift in the NW African plate

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Keywords: Rifting, Inversion, Thermochronology, Atlas, Morocco.

The Atlas Mountains of Morocco are intracontinental fold-thrust belts roughly coincident with the locus of Triassic-Jurassic rifts linked with the Atlantic and Tethys. Triassic rifting is best observed in the basement-dominated massif of the Marrakech High Atlas. NE-SW-oriented synsedimentary faults are steep and bound small, discontinuous grabens filled with red beds, basalt and occasional evaporite. Uplifted horsts that have remained as highs during much of the Atlas history are detected by thermochronology. The Atlantic margin in the westernmost Atlas evolved in continued post-rift subsidence since the beginning of the Jurassic, whereas rifting persisted in the High and Middle Atlas during the early and mid Jurassic defining a system oriented at high angle to the margin. Carbonate and shale sedimentation was partitioned by a polygonal system of diapiric ridges enclosing rapidly subsiding minibasins. A hitherto unexplained episode of uplift during the late Jurassic-early Cretaceous created a belt of exhumation between the Atlantic margin (which still subsided) and the Atlas and Moroccan Meseta; erosion in the Marrakech High Atlas removed up to 2 km of rock and erased the traces of the Jurassic rift. Discontinuous redbeds with frequent hiatuses formed in the central and eastern High Atlas, contemporaneous with a voluminous pulse of alkaline magmatism. Cretaceous post-rift sedimentation is expansive on the basin margins (Anti-Atlas and Meseta). The earliest indices of orogenic-driven exhumation in the High Atlas have been detected by ZrHe thermochronology at ca. 80 Ma. However, paleogeographic reconstructions indicated that clear foreland basin deposits do not occur until the late Eocene. Syntectonic unconformities and conglomerate bodies in the Ouarzazate foreland basin and adjacent thrust belt together with AFT and AHe data document the main phase of compressional deformation and uplift from late Oligocene?-Miocene to recent times. Crustal thickening only partly explains the high topography of the Atlas Mountains. An episode of long-wavelength uplift accompanied by renewed alkaline magmatism was superimposed since the late Cenozoic.

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Tectonics and topography of the Moroccan Atlas II: crust and mantle structure and the support of high mountain elevation

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Keywords: Topography, crust, mantle, uplift, Atlas, Morocco.

The high topography of the Moroccan Atlas Mountains, with large areas above 2000 m of mean elevation and summits reaching 4000m, has long intrigued geoscientists and has spurred numerous geophysical studies in recent times. Balanced geological cross-sections across the Atlas belts indicated modest amounts of tectonic shortening (generally >20%), and a lack of correlation between shortening and topographic elevation. This suggested that crustal thickening alone could not account for the high topography observed, and pointed to a generalized state of isostatic uncompensation at the crustal level. Gravity surveys and the wide-angle SIMA seismic experiment showed a crust of ca. 35 km under much of the High and Middle Atlas, only locally reaching 38-40 km in a small crustal root. Combined modeling of potential fields (gravity, geoid and surface elevation) revealed an asthenospheric high under the Atlas, where the LAB is at ca. 80 km depth. A dynamic support of the Atlas topography is recently confirmed by passive seismic studies. The thinned lithospheric structure contributes to explain the high topography and the Atlas Neogene magmatism, and also accounts for other singular features and the absence of foreland basins almost everywhere. Its origin has been attributed to delamination of a former lithospheric root by some, by lateral dragging by others, while by other authors it responds to a thermal upwelling or a plume-like feature in the upper mantle, pushed aside by the subduction zones of the Gibraltar arc. The timing of lithospheric thinning and the related long-wavelength surface uplift are also a matter of diverse conceptions. Indirect evidence is provided by the initiation of alkaline magmatism starting 15 Ma ago and persisting until the Quaternary. On the other hand, paleoelevation markers tell that the uplift may be delayed, mostly occurring in the past 5 my. Thermochronology does not unequivocally resolve it as the signal of mantle-driven uplift is mixed with that of contemporaneous compressional crustal thickening. River geomorphology indicates the drainage network of the Atlas is in a transient state of reorganization due to ongoing surface uplift and increase of regional slopes. The compressional deformation and mantle-driven uplift signals may be both identified in the process.

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A Bayesian approach for seismogenic stress field computation in the Calabrian Arc region

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Keywords: focal mechanism, stress tensor, Calabrian Arc.

A high-quality waveform inversion focal mechanism database for the Calabrian Arc region has been compiled by integrating data available from literature and catalogues (Orecchio et al., 2014; Totaro et al, 2015; http://www.ingv.it) with 146 new solutions computed in this study by applying the Cut And Paste method (Zhao & Helmberger, 1994). To this massive database (444 solutions) a Bayesian algorithm (Arnold & Townend, 2007) furnishing the posterior density function of the principal components of stress tensor and the stress-magnitude ratio has been applied. Before stress computation, we applied the k-means clustering algorithm to subdivide the focal mechanisms catalog on the basis of each earthquake location. The obtained database and the Bayesian algorithm allowed us to provide a detailed picture of seismotectonic stress regimes acting in this very complex area where lithospheric unit configuration and geodynamic engines are still strongly debated (Devoti et al., 2008; Faccenna et al., 2014). Our results well constrain the extensional domain characterizing the Calabrian Arc and the compressional one of southern Tyrrhenian (Presti et al., 2013; Montone & Mariucci, 2016), while previously undetected transcurrent regimes have been identified in the Ionian off-shore of the study region.

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SESSION S12

Quaternary study: integrated approaches, constraints and open questions

CONVENERS AND CHAIRPERSONS

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Biostratigraphical constraints of the youngest marine deposits at the southern margin of the Central Anatolian Plateau (CAP, Turkey): a key to evaluate the long-term uplift rate of the CAP southern margin

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Keywords: Southern Anatolia, Eastern Mediterranean, biostratigraphy, Pleistocene, foraminifers, nannofossils.

At the southern margin of the Central Anatolian Plateau (S-CAP), the GÜLE section (Gülnar, Mersin) is located at 1000 m a.s.l. It consists of Neogene marine deposits, which unconformably cap the central Tauride basement rocks. The GÜLE section represents the youngest marine deposits of the S-CAP. Herein, we present new data based on biostratigraphy and paleodepth studies of those marine deposits.

Our new biostratigraphical constraints are from micropaleontological studies carried on benthic and planktonic foraminifers, ostracods, and calcareous nannofossils. The calcareous nannofossil analyses show the occurrence of medium *Gephyrocapsa* (First Occurrence at 1.73 Ma) at the base of the GÜLE section. The *Globorotalia crassaformis* influx at 1.72 Ma matches with this occurrence. Furthermore, up in the section, the occurrence of large *Gephyrocapsa* points to an age of 1.617 Ma. Above, among the benthic foraminifers, the First Occurrence of the modern morphotype of *Bulimina marginata* (1.543 Ma) was detected. The ages of these bioevents in the section are consistent with the possible age of a cluster of 5 sapropel layers recognized within the GÜLE section, allowing us to cross-correlate them with the sapropels of the Vrica section, the boreholes of Singa, and the ODP Site 967. These correlations point to consider the sapropel ages of the GÜLE section between 1.642 to 1.564 Ma. The upper part of the section is marked by the FO of *Globigerinella calida* that is dated in the Mediterranean around 0.78 Ma close to the Bruhnes/Matuyama transition. This bioevent is possibly followed by the Last Common Occurrence of the *Neogloboquadrina* spp. (sin), which points for the upper part of the section to an age of 0.61 Ma. The ages that came out from this study let us to evaluate the sedimentation rate of the section. The paleoenvironmental reconstruction was performed by using ostracod and benthic foraminifer assemblages, which let us to identify the paleodepth of the marine environment just before the uplift of the S-CAP. Our findings show that the co-occurence of *Bythocypris producta*, *Paijenborchella iocosa* and *Parakrithe rotundata* indicates water depth around 500-700 m. Among benthic foraminifers, the abundance of *Uvigerina* spp. also confirms similar water depths.

As a result of this study, the provided paleodepth and time constraints were found to be very strong tools to evaluate uplift rate of the S-CAP. The constant sedimentation rate of the GÜLE section allowed us to mark the top-most part to be 0.52 Ma, suggesting a 2.9 mm/yr uplift rate for the S-CAP.

Seismostratigraphic features of the Quaternary Salento shelf (southern Italy): basic characters coming fro the "VIDEPI Project" database

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Keywords: seismostratigraphy, quaternary shelf, salento, videpi project.

The eastern Salento offshore (Apulia, southern Italy) is characterized by a wide Quaternary shelf crossed by seismic lines acquired during the 1960-70 and now available on-line (Videpi Project). Interpretation of the lines has highlighted the occurrence of seismostratigraphic features (clinoforms, parallel, divergent, weavy, transparent and chaotic seismic facies) that could be compared with those observed and defined by Kertznus & Kneller (2009) along the Ebro Continental margin. Both shelves are characterized by a complex pattern of well developed, highly progradational and aggradational, margin-scale clinoforms.

Seismic interpretation related to the Salento shelf has been carried out on a 2D line-by-line basis, and on a 3D grid of 2D lines, developed using the software Move (Midland Valley Ltd.). The prograding sequence has been tied with the Merlo 1 well and generically referred to Pleistocene. Clinoforms with moderate- to high-amplitude reflections occur on seismic profiles orientated along depositional dip direction, whereas divergent reflectors on seismic profiles oriented strike.

Considering the difficulty to acquire new seismic data along the offshore of the Italian peninsula, also vintage seismic line of the Videpi Project could give useful information for the interpretation of Quaternary shelves evolution, like that surrounding the Salento peninsula.

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"We saw things in the sea that you people could not even imagine ..."

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Keywords: sea level, open questions, tidal notch.

We would like to discuss some recent results which have been proposed but not accepted by the Italian scientific community regarding pre-LGM changes in sea level. First, the question which regards the altitude at which today are carved the fossil marine transgressions MIS 5.1 and MIS 5.3 in the Mediterranean sea. These transgressions, called "Neotirreniano", were generally attributed to shares slightly lower than the Tyrrhenian (MIS 5.5) to 6-8 meters, until few years ago. A research, published in Science (Dorale et al., 2010) and on phreatic speleothems in Mallorca, set the MIS 5.1 at +1 m asl. Researches carried out on speleothems (Dutton et al., 2009), on cores (Amorosi et al., 1999) andon deposits and submerged forms (Antonioli et al., 2016, Gzam et al., 2016) indicated depths ranging between -20 m and -10 m bsl for the 5.1 and 5.3 stage, according with the global curve. On the contrary, Mhus et al. (2015) disproved that in Mallorca MIS 5.1 is at the afore mentioned altitude of + 1 m asl. In the Mediterranean basin, the fossil tidal notch is one of the most accurate marker of the sea level occurred during the MIS 5.5. Although it shows difficulties in its direct dating, from the geomorphological point of view , it presents the smaller error bars compared with other sea-level markers, such as corals, speleothems, etc. (Ferranti et al., 2006). The study of the present shaping of tidal notches indicates that they are carved by the combined action of several mechanism. Notwithstanding this, it has been demonstrated that their genesis is strictly connected to the sea level position and their depth is amplified by the exposure to the wave action but this not condiction their width that is in direct relation to the tidal range (Antonioli et al., 2015) The comparation of last interglacial and present notches surveyed in same localities shows that their widths are similar, suggesting that processes responsible of their shape are not changed during the last 125 ka confirming the validity of their use in the identification of the past sea levels.

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Geomorphological investigation of active tectonics: case studies from the southern Apennines

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Keywords: geomorphology, active tectonics, surface deformation, southern Apennines.

The shape of Earth surface in tectonically active regions is dictated, at any scale, by the interaction of endogenic and exogenous processes. Both groups of processes include large varieties of types, which may act through different modes and rates, resulting in a largely variable expression of deformation at the surface.

The classical approach to the detection of surface deformation is based on geomorphological investigation that may effectively succeed in identifying both active and capable faults. In particular, such an approach is crucial to the identification of those faults that are, e.g., quiescent over time periods that are longer than the historical record, or creeping faults.

Detail scale geomorphological investigations carried out in the southern Apennines have allowed identifying “active” faults in different lithological settings (i.e., areas dominated by both resistant and weak bedrock) and in both more and less sensitive geomorphological environments (e.g., alluvial plains vs. mountainous areas, etc.). Based on a variety of indicators of surface displacements, recent - late Quaternary - differential vertical motions along faults have been recognized both in the most seismically active belt, which roughly follows the southern Apennines mountain belt axis, and in areas that are characterised by sparse and/or low historical seismicity. In several instances, surface and shallow subsurface stratigraphical data have provided chronological constraints to fault activity and long term mean slip rates. Furthermore, data from remote sensing techniques (e.g., satellite interferometry) have provided information on current deformation associated with some of the faults identified through the geomorphological analysis.

Case studies from the analysed region (e.g., Amoroso et al., 2014; Ascione et al., 2013) point out that both the spatial distribution and type of offset of active fault segments at the surface provide a reliable picture of deep-seated seismically active volumes. On the other hand, such case studies also suggest that single fault segments at the surface do not represent the net projection of deep-seated faults as they are reconstructed by seismological data, and further point out that the reconstruction of a comprehensive active tectonics framework rests on the combination and integration of different - surface and subsurface - data sets.

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Reconstruction of the buried lava bedrock in the Sarno River Plain (Campania Region)

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Keywords: Geoarchaeology, Quaternary stratigraphy, Geomorphology, southern Apennines, Sarno River Plain.

Geological and stratigraphical data from hundreds of shallow wells and archaeological sites provide the opportunity to investigate the subsurface geology and to reconstruct the geoarchaeological landscapes in the south and eastern footslope of the Vesuvius volcano, and in the neighbouring Sarno River Plain. The shallow subsurface information has been integrated with analysis of detail scale topography data of the Sarno River Plain and adjacent Vesuvius footslope. The shallow subsurface stratigraphical setting of the Sarno River Plain, the features of the various superficial soft units, and the spatial relationships among these units have been reconstructed by means of numerous cores. Such stratigraphical data provide an unprecedented look at the features of the buried lava bedrock that defines the northwestern subsurface margin of the Sarno River Plain.

The lava bedrock surface is exposed at several sites around the archaeological area of Pompeii, however it becomes completely buried moving towards the south and east. The reconstruction of the archaeological landscapes in the Sarno River Plain indicates that only a few thousands year ago, lava outcrops were much widespread than at Present. Below the gently sloping Vesuvius footslope, hidden beneath approximately 10 to 30 meters of Quaternary sediments (tephra and palesoils), is a complex array of buried units composed of volcanic rocks, sandbars, dune ridges etc. Moving across such an array, the Romans were able to quarry lava outcrops at the base of the Pompeii lava cliffs as well as at the base of the Oplonti marine terrace. Iron age pirogues floating from the fluvial village of Longola to the Sarno River mouth were able to collect lava pebbles from outcrops located along the flanks of the valley that, by that time, the Sarno River had incised.

Late Paleolithic lava effusions are also identified as south as Scafati and as east as Palma Campania, where evidence of such volcanic bodies is still preserved at the surface. Relicts of Late Palaeolithic sand/gravel pyroclastic ridges and back-dune lagoons are still detectable. This gravel unit is only composed of volcanic scoria clasts lacking any sandy or silty matrix. Deposition of calcareous tufa bodies seems to be triggered or at least strongly influenced by major volcanic activity.

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Subsurface 3D modeling of Giumentina Valley (Majella, Abruzzo, Italy) trough multi-methodic geophysical surveys

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Keywords: Geophysical Survey, ERT, HVSR, 3D modelling, Giumentina Valley.

Into an archeological study of Giumentina Valley, near Caramanico Terme (Majella, Abruzzo, Italy), we performed a multi-methodic geophysical survey with the aim to delineate the geological setting. This is an ancient valley-basin whose riverbed was carved in Cenozoic limestone and has been filled with fluvial, lacustrine and slopes detrital sediments. Its geological history is closely connected to the evolution and the morphogenesis which affected the northern side of the Majella Massif in the last million years. In fact, the Giumentina Valley is a hanging valley originated as a consequence of paleogeographic variations that have led to the formation of lakes and marshes as well as the formation of endorheic karstic structures in some points of the abandoned riverbed.

In order to reconstruct the stratigraphy along the valley we planned 6 Electrical Resistivity Tomographies and 24 single station passive seismic surveys. The ERT allowed to obtain 6 2D sections of the subsurface, longitudinally and orthogonally respect to the valley; trough HVSR survey we collected few points above the lines (to estimate an average shear velocity value of the alluvial and lacustrine deposits) and others scatter across the valley (away from the lines) to estimate the top marly-limestone bedrock depth. We utilized also a borehole log (located at north of the valley) to constrain the ERT interpretation and HVSR direct modeling.

Trough the thickness of the different deposits units detected by geophysical surveys and starting from the actual DTM (digital terrain model), we calculated respective paleo-DTM of the marly-limestone bedrock and lacustrine top unit.

The spatial localization of the 2D ERT and HVSR, performed by an RTK GPS survey, allows to know the spatial position of subsurface limits for the different deposit units. Trough an appropriate interpolation of these points is possible to generate the DTM representing different geological surfaces detected.

Geophysical surveys performed, allowed to discriminate the stratigraphic sequence because of the different resistivity values for the lacustrine and alluvial deposits with a maximum thickness away from Morrone mountain. Furthermore the ERT method showed a buried doline at the center of the valley in accord with other similar forms into the area. With the actual knowledge is not possible to interpret more about carbonatic formation also with visible different resistivity.

The initial aim, stratigraphic reconstruction of the deposits and 3D subsurface geometry of the valley, has been performed with a degree of uncertainty due to the geophysical spatial sampling, respect to the geological variability. However, it is possible to sustain that for this purpose, the spatial distribution of the 2D ERT and HVSR realized allowed to delineate the geological setting of the Giumentina Valley.

It is under evaluation a seismic reflection/refraction survey to better delineate lithological and structural shapes of Giumentina Valley.

Quaternary climate variations as defined by a coralgal bioconstruction and associated microbialites (Tyrrhenian coast of Calabria, Soutehrn Italy)

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Keywords: Coralgal bioconstruction, palaeoenvironment evolution, Pleistocene, endolithic microbialite.

Four bio-sedimentary facies have been recognized in the Quaternary deposits outcropping at Punta Diamante (Tyrrhenian coast of Calabria, Southern Italy): 1 - *C. caespitosa* bafflestones: the most continuous coral body is composed of contiguous colonies, up to 30 cm high and of about 50 cm in diameter (Is-index about 0.6), in part coalescent, forming a bank ~1.5 m in thickness; colonies are sub-hemispherical and show a phaceloid morphology. 2 - Red algae bindstones: lithophylloidae crustose coralline red algae occur as a secondary frame-builder associated with *Cladocora caespitosa* bafflestone; *Titanoderma* sp. (Nägeli, 1858) is the most common species, with subordinate *Lithophyllum* sp. (Philippi, 1837). These two facies together form the coralgal bioconstruction unit. 3 - *Spondylus gaederopus*-rich boundstones: numerous right valves of the bivalve *Spondylus gaederopus* (Linneo) are included in a lithified boundstone composed of red-algae and microbialites; encrusting red algae form rhodoliths up to ≈ 5 cm in diameter and associated microbialites are composed of peloidal to aphanitic micrite that fills remaining cavities. 4 - Endolithic microbialites: several cavities within the bioconstruction are partially to totally filled with micritic carbonate deposits, reddish to yellow in colour.

The coralgal bioconstruction associated with *Spondylus gaederopus* sp.-rich boundstone, formed as a result of submergence during Marine Isotope Stage 9 in a moderate shallow-marine environment at a depth of 6 - 20 m. The coast was affected by moderate to high-energy currents and occasional storms; the annual temperature was 12° - 18°C. The lower part of the coralgal body is dominated by *Cladocora* and the upper part by Lithophylloid algae. The change was likely the result of the occasional influx of coarse clastic material that partially buried the *C. caespitosa* colonies, but provided a suitable substrate for the pioneer encrusting organisms. During a subsequent glacial stage, sea-level fall combined with tectonic uplift induced the partial emergence of the coralgal body, and deposition of an overlying subaerially-deposited breccia. A later resubmergence of the area, likely during the last interglacial period (MIS 5), is recorded as testified by the presence of endolithic microbialites in cavities within the coralgal bioconstruction and the breccia deposit. Microbialite formation took place in a marine environment with cooler water, with respect to the previous submergence phase, possibly during a time of early deglaciation. The low temperature, possibly combined with very shallow depths and an excess of nutrients, could have played a role in preventing further growth of *C. caespitosa* while favouring the precipitation of microbial carbonate.

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Lake Trasimeno's Quaternary vegetation and climate history from palynological studies

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Keywords: Quaternary, lacustrine setting, palynology, paleoenvironment, central Italy.

During the last years the Lake Trasimeno (LT) has been the object of multidisciplinary analyses aimed to reconstruct its Quaternary paleoenvironmental history. Here we present the results of palynological analyses carried out in:

1. selected sediment samples from the 175 m long core drilled by the Regione Umbria Geological Survey along the south-eastern coast of LT (Perugia, Umbria - 49°09'N; 12° 06'E, alt. lake bottom 251.57 m a.s.l.);
2. seven samples collected from the bottom-water interface along a transect at different depths (between 2 m and 6 m) and distances from the LT coast.

Palynological analyses in the core samples have been carried out in order to define the history of paleoenvironmental and paleoclimate changes by the analysis of the floristic composition and vegetation structure, as well as to contribute to the definition of the chronostratigraphic context of its sediment infill. The overall palynological record confirms the presence of phases of expansions of open environments characterized by a dominant herbaceous vegetation (Asteraceae including *Artemisia*, Poaceae and Chenopodiaceae) alternating to phases of expansion of a mixed-oak forest (mainly deciduous *Quercus*, *Ulmus/Zelkova*, *Carpinus*, *Corylus* and *Fagus*). A revision of the upper portion of the core has been also carried out to verify the occurrence and the abundance of some taxa such as *Carya*, *Pterocarya* and *Tsuga* which are known to disappear by the Italian peninsula under the effect of glacial-interglacial cycles since the Middle Pleistocene. This statement is especially relevant with respect to the still open question concerning the chronology of the LT sediment infill.

The palynological analysis of the bottom-water interface samples gives us the possibility to explore the relationship between the (sub)modern pollen assemblages and the contemporary vegetation from the catchment area; this is also a key for a better comprehension of the fossil pollen record. Such study is particularly important because of the peculiar features of the LT which is the largest lacustrine system of central Italy and the fourth Italian lake in size (~120 km^2), a shallow (average depth 4.7 m, maximum depth 6.3 m) endorheic lake with very few small tributaries. The seven samples were treated using a standard chemical-physical procedure and analyzed at the optical microscope, at the Laboratory of Palynology of Florence. All samples are very rich in pollen grains but also in algae as well as other non-pollen palynomorphs (e.g. *Pseudoschizaea*, *Pediastrum*, *Botryococcus* and *Glomus*). Among arboreal taxa deciduous Quercus is very abundant; among herbaceous plants Poaceae and Asteraceae are both well represented. The results from the fossil pollen record will be here presented and integrated by the taphonomic evidence from the (sub)modern pollen spectra.

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The TEA C6 record: a reference archive from the Gulf of Taranto (Ionian Sea) for the last 15 ka

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Keywords: Gulf of Taranto, sedimentology, petrophysics, micropaleontology, geochemistry, tephrochronology.

An integrated stratigraphic analysis was carried out on the TEA C6 gravity core raised from the Amendolara basin in the Gulf of Taranto. The 4.5 m long succession was investigated by means of sedimentology and textural analysis, petrophysics, micropaleontology and geochemistry with a refined dating framework provided by oxygen isotope, tephrochronology and ^{14}C AMS ages. Textural and micropaleontological data were analysed by means of Compositional data analysis. The results pointed to a deep marine record with no or little disturbance and they aimed to contribute to the reconstruction of the palaeoceanographical and paleoclimatic changes occurred in this sector of the Central Mediterranean during the last 15 ka BP. In particular, data obtained along the sapropelitic interval corresponding to the Sapropel S1 deposition (9.6-7.5 ka BP), offered a detailed insight on the conditions that characterised the study area during this phase. The deposit was sampled with a continuous step of 1 cm-slides of sediment and this allowed to have resolution even in the order of 50 years. During the early Holocene, before the onset of Sapropel deposition, foraminifera show evidence of several centuries characterised by persistence of winter mixing and likely summer eutrophication. The weakening of winter mixing is simultaneous with a change in bottom conditions, leading to the dominance of oxygen resistant species and then to the establishment of anoxic conditions. During this phase, truly onoxic conditions alternate with periods of partial recovery of benthic faunas, the longest of which correspond to the Sapropel S1 interruption. This moment is time fixed by the occurrence of a tephra layer interbedded within the marine deposit. The end of the Sapropel S1 phase coincides with the re-establishment of winter mixing, although eutrophication persists during a transition interval 400 years long. Dynamics and duration of Sapropel S1 in the Gulf of Taranto show similarities with those of the Adriatic Sea. Sea Surface Temperatures (SST) recontructions obtained from planktonic foraminifera by means of CoDaMAT indicate during the stadial GS1 (Younger Dryas) summer and winter SST about 12°C and 7°C lower than present, respectively, and Holocene SST fluctuations in the range of 2°C. According to the results, TEA C6 core might represent a reference archive for the Gulf of Taranto in terms of response of the sedimentary environment to palaeoceanographical and paleoclimatic changes from the late glacial to the late Holocene.

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Quaternary tectonics from seismic interpretation and its relation with deepest geothermal fluids in the Marche region (Central Italy)

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Keywords: Quaternary tectonics, geothermal fluids, seismic interpretation, Apennine chain, Marche region.

In the evaluation of the geothermal exchange potential, knowledge of the structural features is essential to modelling geothermal systems. Faults and fractures play an important role in the circulation of fluids in the crust, and the nature of that role varies according to structural setting. In particular, structural control influences groundwater flow, its regime, chemistry, and electrical conductivity (Hoffmann-Rothe et al., 2004). As a result, data coming from accurate studies of groundwater physical properties in the Marche region (electrical conductivity above all), revealed some anomalies in several localities that could be ascribed to a strong structural control. The interpretation of some ENI SW-NE seismic profiles crossing the Apennine chain to the Adriatic sea, highlights important deep Plio-quaternary structures probably connected with the minor surface ones as well as to hydrogeological conditions. By means of seismic profiles interpretation some NW-SE sub-parallel transpressive structures, formed by SW and NE-dipping high-angle reverse faults reaching > 10 km depth (positive flower structures), and then probably involving the upper crust basement, have been identified. Locally, at the axial zone of these transpressive structural highs, Upper Miocene (Messinian) evaporite deposits outcrop as a result of the lifting and the counter-clockwise rotation of the Pre-Pliocene substratum blocks, clearly caused by sub-vertical SW-dipping reverse faults. The coastal structural high have a dual role, on the one hand it prevents the ingression of sea waters and on the other should be an important factor in explaining the increased electrical conductivity values of groundwater, and their direct relation with the amount of rainfall revealed from studied piezometers in the area. It should be explained through a specific behaviour like that typical of carbonate aquifers, known as the “piston-flow phase” (Banzato et al., 2014). This process implies an increase of groundwater mineralization as a result of transmission of the hydraulic pressure from the saturated zone, through fractures as important way for fluids circulation. Here is then suggested that the structural control could be an important factor in influencing both the surface and the groundwater flow behaviours, and then convective component of the heat transport.

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Holocene evolution of the Sibari Plain (Southern Italy) in a tectonics controlled setting

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Keywords: Sibari Plain, late Quaternary, Electrical Resistivity Tomography, Crati Delta.

The Sibari Plain is located close to the boundary between the Calabrian Arc and the Southern Apennines. During the Holocene, the plain was characterized by the Crati delta building and by the re-activation of the transverse Sybaris Fault Zone (SFZ), a northward dip fault interpreted as an oblique normal-dextral fault zone, 45°N–55°N striking, recognized by archaeoseismic data recorded in the Sybaris ruins.

We carried out a muldisciplinary approach combining boreholes stratigraphy and ancient cartography analysis and acquisition of 2D Electrical Resistivity Tomography (ERT). We identified four main units: (1) the Late Pleistocene sandy-gravelly alluvial and coastal plain deposits, (2) early-middle Holocene clayey sediments of marine-marshy-lagoon origin, (3) a middle-late Holocene sandy beach ridge system and (4) late Holocene deltaic sediments. The elevation contours of the top for the Pleistocene basement reveal a Holocene SFZ activity or reactivation that has probably created space for a different arrangement of late Pleistocene and Holocene units in the surrounding Crati River area. Furthermore, an ERT allows to observe evidences of the SFZ close to Sybaris.

Considering the different stratigraphic units thickness and association, we suggest that the SFZ Holocene activity drove the plain evolution influencing the development of different depositional environmental conditions between hanging wall and footwall. In detail, major *delta-building* events reconstruction suggests that at the end of last-glacial transgression (around 6 kyr B.P.) a wide wetland and a shallow water bay environment took place on the hanging wall. On the foot wall, the Crati River built its terminal plain and its delta. Up to Sybaris time (2.7-2.5 kyr B.P.), the high subsidence on the hanging wall favoured the deposition of thick wetland deposits passing seaward to the shallow water sediment of the coastal embayment. At the same time, on the foot wall the Crati Delta progradation went on reaching the area southward from the Sybaris settlement. Up to the present day, the tectonics has been influenced the plain topography, producing a depressed area on the hanging wall, marked by widespread presence of humid zones. The present confluence between Crati and Coscile Rivers happens in correspondence to the SFZ. We suggest that the the ground-tilting drives the Coscile River channel to avulse periodically toward the SFZ (the down-tilt side with minimum elevation), with the consequent confluence in the Crati River, during the active tectonic period and to move away from the SFZ during quiescent one producing the two rivers separation. The latter can be favored by sediments accumulation close to the SFZ, which re-establish the pre-tilting equilibrium. In conclusion, our approach aims to identify the SFZ as a major agent controlling deposition and landform development by creating accommodation space for the deposition of coastal sediments along Sibari Plain during the Holocene.

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Carbonate speleothems from gypsum caves for palaeoclimatic and palaeoenvironmental reconstructions

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Keywords: speleothems, gypsum karst, U-Th dating, palaeoclimate, landscape evolution.

Carbonate speleothems record a series of environmental and climatic information (McDermott, 2004). Their mere presence in a cave signifies that water was present in the karst system and conditions were adequate to stimulate supersaturation with respect $CaCO_3$. The most exploited geochemical proxies are oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotopes. Furthermore, speleothems are precisely datable. This permits to accurately constrain the time period(s) during which the cave system was capable of producing speleothems and to insert the proxies data into a rigid timeframe.

Although speleothems have occupied a key role in “palaeo” science over the last twenty years (Henderson, 2006), there is a striking gap in the literature. All previous studies have been based on carbonate speleothems coming from limestone/dolostone karst. The potential of speleothems sampled in non-calcareous caves for palaeoclimate and palaeoenvironmental research is essentially unexplored.

In this work we present several applications of the study of speleothems sampled in gypsum caves (Northern Apennines). The U-Th dating of five speleothems grew in the Monte Tondo karst system allowed to evaluate the climate-driven incision/aggradation of the Senio valley at intra-Milankovitch timescale. This study suggests that speleogenetic processes were active during relative cold stages, when the local base level stabilized a new altitudinal position and the scarcity of vegetation on the valley slopes favored the flux of sediments forming the river terraces. On the contrary, speleothems grew during periods of relative warm and wet conditions over the last 125,000 years, and their dating gives the minimal age of the cave where they were found. Furthermore, speleothems were sampled in five karst system nearby Monte Tondo; twenty more samples were dated with the U-Th method (~100 ages produced) and analyzed for $\delta^{18}O$ and $\delta^{13}C$. Our results show that 1) the production of speleothems from gypsum caves responds to strict climatic and environmental parameters; 2) the stable isotopic composition is influenced by the amount of rainfall reaching the cave-site at the time of the formation of the speleothems. Interestingly, some of the speleothems reported an unexpected old age. This permitted the chronological revision of the inception of the speleogenetic activity in the Northern Apennines that, until this date, was considered to be occurred during the last 130,000 years. Caves were instead forming at least 450 ka, ~350 kyrs after the regression of the Adriatic Sea. This lapse was necessary for the erosion of most of the sediments covering the gypsum beds and the maturation of the drainage network, which facilitated karst infiltration in trough sinkholes and blind valleys.

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Late Holocene evolution of a deltaic-lagoon system related to history of the Othoca Phoenician-Punic center (Gulf of Oristano, western Sardinia)

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Keywords: Holocene, delta, barrier, lagoon, geoarcheology.

The Gulf of Oristano (western Sardinia) is a wide bay (150 km^2) bordered by sandy shores which are composed of barrier-lagoon systems, sandy spits, and attached barriers while the backshore is an alluvial plane with lagoons and dune systems. The Tirso River, whose mouth is located in the northeastern sector of the Gulf, is the main source of sediments from the land. The Gulf represents the western boundary of the Campidano graben, a Pliocene-Quaternary structural depression which is oriented NW–SE. This basin is a half-graben with the main depocenter located in the Gulf of Oristano. This area was subjected to an intense exploitation of the coast which occurred during Phoenician, Punic and Roman time, with ancient settlements located along the coast and lagoon shores. In this study, we analyzed the evolution of the delta of the Tirso river and the subsequent evolution of the adjacent Santa Giusta lagoon, in relation to the presence of a main Phoenician-Punic center (Othoca) located along the inner lagoon shore. A set of geophysical data (high resolution seismic data, multibeam data) collected in the gulf coupled to stratigraphic data derived from more than 70 boreholes were analyzed in order to made a litho-stratigraphic and paleo-environmental reconstruction of the whole coastal system during the late Holocene. During the transgression of the sea a wide barrier-lagoon systems formed at the entrance of the gulf and along the Tirso paleo valley in the northern sector. The transgressive surface (TS) was recognized in the inland boreholes and related to the TS of the offshore seismic data. The evolution of Santa Giusta lagoon, which probably conditioned the history of the Othoca settlement, was strictly related to the progradation of the Tirso river deltaic system up to the present coastal settlement, during the last 5 ka. The reconstruction of the lagoon shoreline is very important to reconstruct the history of the ancient city and to interpret the underwater archaeological deposits discovered in the lagoon bottom. and dated between VII and II century BC (2650 and 2150 BP).

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New dating constraints the Catania Anticline active folding by geological and archeological data

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Keywords: Active folding, Holocene, Catania.

In order to remark the evidence of NNW-SSE compressive regime affecting the western sector of Mt. Etna, reveled by seismic occurrence and by active folding at the front of the chain, we present new archeological and geostratigraphyc data which confirm a plicative tectonic style in this area and a large WSW-ENE trending active anticline growing in western sector of Catania town, while also better constrain the time span in which this deformation amount occurred.

The above structure named by the Authors “Catania anticline”, indeed, is a rapidly growing geological feature in the last years but it is also a thrue “geologic” structure. In fact, the lower term of the succession, the Pleistocene marly clays, is located in the axis fold core and maximum upward deformation related to the anticline development estimated in 40 m occurred in the last 7500 yrs, so the vertical slip rate and shortening previously evaluated by geological, morphological and geodetic methods in 6 mm and 5 mm/yr. respectively could be minor.

New stratigraphycs data indicate that the Holocenic alluvial deposits cropping out in the Misterbianco Zona Industriale area and bringing Stentinello age pottery predating the folding activity, are strongly deformed and form a little syncline between the Catania and Terreforti anticlines.

Moreover morphological attitude could be claims an analogue late deformation of the Terreforti anticline eastern tip. The new growing rate of the Catania anticline, inferred by archeological data, indicate a vertical deformation of about 5 mm/yr.

Palaeoenvironmental reconstructions through compositional data analysis: the CoDaMAT method

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Keywords: Compositional data analysis, Modern analog technique.

We present a modern analog technique (CoDaMAT) based on compositional data analysis (Aitchison, 2003). In order to reconstruct palaeoenvironmental parameters, CoDaMAT adopts the Aitchison distance (Aitchison, 2000; 2003), obtained from relative abundances expressed in log-ratios (logarithm of ratios), as a "natural" measure of similarity between modern and fossil assemblages. The number of modern analogs from which obtain the palaeoestimates was determined through cross-validation techniques taking modern assemblages as the training data set. Atypicality index was considered to detect past no-analog conditions. The average of distances and expected maximum estimate errors were taken into account to evaluate the quality of palaeoestimates. The method has been tested on Mediterranean and Atlantic planktonic foraminiferal assemblages to reconstruct past sea surface temperatures (SST). Due to the peculiar oceanographical asset of the Mediterranean, no-analog conditions may represent an important problem in attempting the reconstruction of glacial SST. Keeping in mind these limitations, we obtained for the Tyrrhenian sea, at 15 ka BP (during the Greenland stadial GS2-a), summer and winter SST estimates respectively 12°C and 6°C lower than present. These are the lowest values reached during the last 34 ka. In the coldest interval of the Greenland stadial GS1 (Younger Dryas), reconstructed summer and winter SST were respectively 11°C and 5°C lower than present. In comparison with previous foraminiferal based reconstructions (de Abreu et al., 2003), the CoDaMAT palaeoestimates of Atlantic ocean surface temperatures for the last 200 ka show a stronger coherence with the alkenones and stable isotope record (Pailler and Bard, 2002).

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The timing and spatial pattern of Late Pleistocene-Holocene shorelines uplift in the Calabrian Arc: clues for understanding regional and local tectonic processes

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Keywords: Coastal uplift, Late Pleistocene-Holocene, Earthquake clustering, Calabrian Arc.

Post 0.8 Ma surface uplift of the Calabrian Arc embeds mechanisms from both regional and local sources (e.g. Westaway, 1993). Because of its ~300 km wavelength and spatial coincidence with a NW-dipping lithospheric slab, the regional contribution is thought to arise from a deep crustal or mantle source (e.g. Wortel & Spakman, 2000). Conversely, uplift at ~10 km wavelength is attributed to local sources, generally represented by normal faults.

Large part of tectonic reconstructions have relied on the study of long-term uplift markers, and between those a prime role is assigned to the Last Interglacial shoreline (Ferranti et al., 2006). However, displaced Holocene shorelines indicate average uplift rates consistently higher (65 to 125%) than longer-term rates (Antonioli et al., 2006). Given a background of regional uplift at a maximum of 1 mm/yr (Westaway, 1993; Ferranti et al., 2007), the larger local contribution to uplift has been likely supplied by enhanced slip on faults straddling the Calabrian Arc coastline.

Effectively, a vertical sequence of raised Late Holocene (~6 ka) shorelines at several sites documents the occurrence of abrupt uplift events which are attributed to paleo-earthquakes. Seismic strain release appears clustered during limited time intervals of ~300-500 years when several faults were activated in a cascade fashion giving rise to earthquake storms. These storms are separated by ~400-1400 years of seismic quiescence. Four storms occurred between 6-1 ka, with Me ~6.6-6.9. A more recent storm is documented by historical seismicity between the 17th and 20th century A.D. The large (up to 2 m) uplift per event can be explained either with footwall displacement of normal faults during seismic clusters unresolved in the shoreline record, or with activation of lower crustal thrust faults related to the Ionian subduction.

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Mid-late Quaternary uplift of the coastal sector between Mazara and Selinunte (SW Sicily): hints on the active tectonic structures

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Keywords: Regional uplift, Active shortening, Relative sea-level changes, SW Sicily.

A detailed survey of Quaternary coastal forms and deposits occurring in the area between Mazara and Selinunte (SW Sicily) has been carried out with the aim to unravel the morphotectonic evolution of this sector of Sicily, which spans the transition between the front of the fold and thrust belt and the Sciacca deformed foreland. Although this area has been hit by the destructive 1968 Belice earthquake sequence and by historical earthquakes that caused the recurrent devastation of the Greek settlement of Selinunte (Bottari et al., 2009), there is not yet a clear understanding of the seismogenic structures responsible for these events (Barreca et al., 2014, and references therein). Similarly, the pattern and rates of late Quaternary uplift is still poorly defined (D'Angelo & Vernuccio, 1996; Antonioli et al., 2006).

This work is part of an integrated geological, geophysical and geodetic project devoted to the seismotectonic study of SW Sicily, and is specifically finalized to reconstruct the sequence of uplifted paleoshorelines along this coastal sector. Our objective is to provide better constraints on the regional, vertical tectonic movements , and to disentangle differential motions with shorter wavelength between adjacent coastal sectors possibly related to the vertical displacement of tectonic structures orthogonal to the coast. Previous research evidenced the existence of a tectonic lineament (Castelvetrano-Campobello di Mazara, CCM line) inferred to be the morphological expression of a shallow splay of a crustal thrust ramp (Barreca et al., 2014), which separates the ridge hosting Castelvetrano, Campobello, and Mazara in the hanging-wall to the west, from the Selinunte plain in the foot-wall to the east.

The older Quaternary deposits outcropping in the area are the Emilian p.p.-Sicilian *Calcareniti di Marsala Fm.*, an highstand prograding system formed before commencement of the regional uplift. The mid-late Pleistocene system is composed by a regressive suite of terraced coastal deposits (D'Angelo & Vernuccio, 1996). Notably, wave-cut platforms with minor terraced deposits are found in the hanging-wall of the CCM line (Mazara sector); oppositely, a thick stack of foreshore calcarenites and offshore clays, punctuated by submarine bars evolving to back-beach dunes, fills the foot-wall of the CCM line (Selinunte plain). In both cases, regional uplift is documented by the progressive seaward shift of paleo-shoreline indicators of relative sea-level falls, but the different morphological expression of the two blocks suggests activity of the CCM line. A very recent activity, as already testified by interferometer data and faulted archeological indicators (Barreca et al., 2014), is supported by analysis of the lower (0-30 m a.s.l.) terraces which show relatively higher elevations and a larger number in the hanging-wall. U-Th dating and bio-stratigraphical analyses in progress will hopefully provide absolute age constraints on the age of the terraced flight and motion of the CCM line.

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Climate variability through the Marine Isotope Stage 19 in the Bradano Trough (Southern Italy): a multi-proxy record

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Keywords: MIS 19, Montalbano Jonico succession, terrestrial and marine proxies, orbital and millennial scal

A multiple paleoclimate approach from Quaternary crucial time intervals within sensitive areas gives the opportunity to extend knowledges on climate behavior and therefore to improve future predictability. In this context a multi-proxy high resolution data-set based on calcareous plankton, dinocysts, pollen, mineralogy and grain size has been acquired, across the interval including MIS 19, from a portion of the marine on land Montalbano Jonico succession (Bradano Trough, Southern Italy), a candidate to host the Global Stratotype Section and Point (GSSP) of the Middle Pleistocene. The results highlight an interesting climate orbital and millennial scale variability well expressed by the vegetation changes occurring in the borderland area, the nature of the sediment supply into the basin, and by the sea surface water features. The cross-examination of both continental and marine proxies within a single record was valuable to recognize mode and timing of on land and marine response to climate variability and to identify the local vs global climate signatures. Calcareous plankton reveals to be primary affected by modifications in sea surface temperature, although water stratification, salinity, turbidity and nutrient content also influence the distribution of selected taxa. Subpolar/transitional to temperate/subtropical surface water conditions alternate through the record and reveal a remarkable correspondence with the recurrent changes from steppe and halophytic vegetation to prevalent expansions of thermophilous arboreal populations on land. Mineral composition of sediments, although clearly reflecting the features of the outcropping units in the source area, appear also in relation with vegetation, hydrological and climate changes. Aridity on land and related reduced arboreal vegetation during colder phases likely promoted erosional processes on the hillslopes and terrigenous supply. Conversely, climate phases characterized by mild winters and warm summers, with reduced seasonal moisture deficiency, promoted chemical weathering on land. Grain size distribution matches climate phases clearly reflecting the climate induced transgressive/regressive phases and the consequent more distal/proximal setting of the study section. The identified millennial scale variations provide valuable insights on the climate pattern across MIS 19 and on the potential similarities with its closest Holocene analogue. The overall results suggest that the investigated section preserves a climate variability strictly comparable with the multiple events of ice sheet growth and subsequent instability identified in both Greenland and Antarctic records and strengthen an atmospheric/oceanic connection in the Middle Pleistocene to millennial-scale Northern Hemisphere ice-sheet instability.

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The aggradational successions of the Aniene River Valley in Rome: evidence for the oldest Neanderthal presence in Europe

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Keywords: Neanderthal, lithic industries, paleontology, aggradational successions, geochronology, Rome.

We revise the chronostratigraphy of several sedimentary successions cropping out along a 5 km-long tract of the Aniene River Valley in Rome (Italy), which yielded six hominin remains previously attributed to proto- or archaic Neanderthal individuals and a large number of lithic artefacts showing intermediate characteristics between Acheulean and Mousterian cultures. In particular, hominin remains were collected at four localities: Saccopastore, Casal de' Pazzi, Ponte Mammolo and Sedia del Diavolo. Through a method of correlation of aggradational successions with post-glacial sea-level rises, relying on a large set of published 40Ar/39Ar ages of interbedded volcanic deposits, we demonstrate that deposition of the sediments hosting the human remains and the associated lithic industries span the interval 295 - 220 ka, providing the most precise ages for direct Neanderthal evidence in Europe. In addition, the associated vertebrate fauna from the above-mentoned localities is quite homogeneous and is characterized by the presence of *Cervus elaphus rianensis* (only recorded during the late Middle Pleistocene in Italy) and *Equus hydruntinus* and *Dama dama tiberina* (both occurred for the first time in Italy in Italy during MIS 8.5; Marra et al., 2014), which suggest a late Middle Pleistocen age for the fossiliferous levels. Based on these ages and the concentration of remains within such a small area, the hominins that have left their traces within these sediments should be regarded as the oldest Neanderthal evidences in Europe, discovered at date. In fact, available age determinations on the Neanderthalian fossils in Europe are often contrasting, depending on the applied dating method, and are indeed poorly constrained, with associated errors in the order of several tens of thousand years (e.g.: Gamble, 1999; and references therein). The oldest Neanderthal evidence in Europe, based either on the lithic industries or cultural aspects, has average ages ranging 250-230 ka, but errors as large as 76 ka. Our method of correlation allows us at providing well constrained ages for the human remains that have been recovered within the aggradational successions deposited in response to the sea-level rises occurred 295, 270, 245 and 220 ka.

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New constraints on the Plio-Quaternary deposits of the Collepardo area (Ernici Range, Central Apennine, Italy)

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Keywords: Mammal biochronology, Continental deposits, palaeomagnetism, geochemistry.

One of the main questions regarding the evolution of the Apennines is the dating of the coarse continental (conglomerates and breccias) Plio-Quaternary sediments uncomfortably covering the pre, syn and late orogenic deposits. These sedimentary bodies are usually referred to a variety of depositional environments from fluvial to lacustrine, including alluvial fans, debris flows and rockfalls. They are characterised by fragmented outcrops, due to the scarce lateral continuity of their depositional environments as well as the natural erosional processes. Moreover, their chronological definition is challenging. In absence of material related to volcanic activity, their dating is linked to occasional findings of fossil remains more than to the application of numerical dating methods, limited by the absence of suitable material or by the restricted chronological intervals covered by the different methods.

A recent geological survey on the SW flank of the Ernici range, led to the identification and rediscovery of the Collepardo fossil bearing site (Segre 2004). The abundant fossil vertebrate remains occur within a complex sequence of travertines and breccias, never described and studied before. The Collepardo faunal assemblage includes large mammals such as the rhino *Stephanorhinus* cf. *S. jeanvireti*, the suid *Sus* sp., the cervid *Pseudodama lyra* (cervids were the only group studied in detail by Segre Naldini & Valli, 2004), the rare caprine *Hemitragus* sp. and carnivores (the raccoon dog *Nyctereutes megamastoides*, the sabertoothed cat *Megantereon* sp., Felidae and Ursidae). The ongoing revision of the fossils, stored at Istituto Italiano di Paleontologia Umana (IsIPU) laboratories at Anagni, and of the new findings supports the attribution of the assemblage to the Pliocene. A detailed geological survey coupled with geochemical and palaeomagnetic analyses has led to a more detailed chronological definition of the Fauna assemblage.

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CET1 core: a multiproxy correlation of marker events in the eastern Tyrrhenian Sea

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Keywords: ecostratigraphy, tephrostratigraphy, 40Ar/39Ar dating, EasternTyrrhenian Sea.

A detailed integrated stratigraphic framework was obtained in the eastern Tyrrhenian Sea (central Mediterranean) through quantitative analyses of planktonic foraminifera assemblages, tephrostratigraphical studies and $\delta^{18}O$ measurements on the basinal CET1 cored succession, spanning the last 105 ka. For the last 40 ka relative abundance fluctuations in the planktonic foraminifera assemblages allowed the identification of nine known eco-biozones and several bioevents recognized in the Tyrrhenian area and that are useful for correlations between Mediterranean marine records. Compositional changes in the planktonic foraminifera assemblages together with variations in the oxygen isotope record allowed us to detect the major climatic global fluctuations and some of the minor events that occurred during the investigated time interval.

A total of 25 visible tephra layers and cryptotephras have been recognized and correlated with their volcanic sources and/or with known explosive events of Campanian and Sicilian–Aeolian volcanoes. A stratigraphic relationship between foraminiferal and climatic events and tephra layers has been highlighted. For the first time ecostratigraphic and tephrostratigraphic methods were combined to obtain a detailed integrated stratigraphy for the last 40 ka in the Tyrrhenian area, and the recognition of the stratigraphic relationship between bioevents and tephra layers enhances the possibility for reliably correlating marine and terrestrial records between different central Mediterranean sites. Starting from 48 ka B.P., we develop a robust chronostratigraphy for the main climatic events and tephra layers in the core and pinpoint tephra markers for the climatic events comprised between GS 22 and GI 24 in the eastern Tyrrhenian Sea. The integration of ecostratigraphy, tephrostratigraphy and oxygen isotope stratigraphy represents a powerful tool for accurate subdividing the late Quaternary Mediterranean marine record. The achieved stratigraphic framework provides a useful stratigraphic reference record for the investigated area.

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Alluvial fan shift reveals Quaternary migration of active extension. A case study in the Northern Apennines of Italy

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Keywords: tectono-sedimentary evolution of extensional basins, alluvial fans.

The space migration of active extensional tectonics through time produces a correspondent shift in the position of the active depocenter. This process produces features like wind gaps, abandoned valleys, streams captures and drainage inversions which provide hints on timing and rate of active tectonics. We take as an example a tectonically active area in the Northern Apennines of Italy where both instrumental and historical seismicity (maximum epicentral intensity I0=VIII) are present and where geodetic extension rates are in the order of 2.5-2.7 mm/yr. In particular, we study the Montefalco ridge drainage inversion where fluvial sands and imbricated conglomerates deposited in a lower Pleistocene depocenter constituted by an extensional subsiding basin, are presently uplifted more than 200 m above the present day alluvial plain. The Montefalco ridge drainage inversion, at about 400 m a.s.l., separates two valleys, the Gualdo Cattaneo - Bastardo valley to the West (300 m a.s.l.) and the Foligno present-day alluvial plain to the East (200 m a.s.l.).

We integrate different data sets collected by field mapping, detailed photo-geological data, sediments provenance information, and subsurface data. Seismic reflection data show that the maximum thickness of the continental sequence in the Foligno valley is in the order of 500 m and is tilted to SE. The valley is presently occupied by a 37 km^2 alluvial fan produced by the Topino river flowing from NE to SW. Surface geology data including paleo-currents measurements of imbricate sequences as long as photogeological data on the uplifted Montefalco conglomerates indicate a flow of the waters with a NE provenance. We interpret the Montefalco ridge as a paleo-Foligno-like alluvial fan representing the evidence of the recent migration of the active extension to the East. At a larger scale, by comparing the distribution and thickness of the Holocene alluvial deposits we find a positive correlation between these and the historical seismicity. We stress the importance of detailed multidisciplinary studies in the investigation of the time-space extension which affects the steadiness/unsteadiness of faults behaviour.

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Plio-Quaternary geological map of the Paganica-S. Demetrio-Castelnuovo Basin (L'Aquila, central Italy)

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Keywords: Pliocene, Quaternary, Paganica-S. Demetrio-Castelnuovo Basin.

The Paganica-S. Demetrio-Castelnuovo Basin (PSCB) is a NW-SE trending Plio-Quaternary graben located in the eastern portion of the L'Aquila Basin. The PSCB is the result of the tectonic activity along the main bounding normal fault systems, as evidenced by the 2009 L'Aquila earthquake, the Paganica-San Demetrio Fault System and Barisciano-San Pio Fault in the northeastern side and the Bazzano-Fossa Fault in the southwestern one. Consequently, for seismic hazard purposes, an in-depth PSCB geological study was carried out with the goal to analyse the relationships between the Plio-Quaternary stratigraphy of the basin and the active tectonic setting (Nocentini, 2016).

Fine-scale geological field surveys, coupled with paleontological data (freshwater molluscs and ostracods), facies analyses, well-logs and geophysical data interpretation, allowed us to fine tune the PSCB stratigraphy and to review the previously described units or synthems (Bertini & Bosi, 1993; Centamore et al., 2006; Giaccio et al., 2012), resulting in the definition of seven synthems, spanning from late Piacenzian to Holocene. In particular the occurrence of a *Caspiocypris* species flock at the base of the sedimentary fill of the PSCB, allow us to suggest that the lacustrine deposits of the *San Demetrio-Colle Cantaro Synthem* could correlate with the late Piacenzian-Gelasian *Fosso Bianco Fm* of the Tiberino Basin, pointing to a late Piacenzian age for the onset of the extension in the PSCB (Spadi et al., 2016). The lacustrine system disappear at the Gelasian-Calabrian transition and the following evolution of the PSCB was characterized by the presence of fluvial and alluvial fan systems progressively entrenched into the lake deposits.

The results of the above mentioned activities are summarised in the presented geological map, where the Plio-Quaternary synthems and the active normal faults accountable for the significant seismicity have been highlighted.

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Plio-Quaternary geological map of the L'Aquila-Scoppito Basin (L'Aquila, central Italy)

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Keywords: Pliocene, Quaternary, L'Aquila-Scoppito Basin.

L'Aquila-Scoppito Basin (ASB) is located in the western part of the wider L'Aquila Basin, an intermontane basin of central Italy showing a significant historical and current seismicity, as evidenced by the April 6 2009 Mw: 6.1 L'Aquila earthquake (Falcucci et al., 2015). The ASB extends from the San Vittorino threshold, to the N, up to the Bazzano-Monticchio Fault, to the S. It is a complex Plio-Quaternary graben bordered to the north by both the south dipping Scoppito-Preturo Fault and the southwest dipping Pettino active Fault.

A multidisciplinary approach was carried out with the aim to reconstruct the ASB tectono-stratigraphic evolution, the regional tectonics, and the climate forcing that controlled sedimentation processes within the basin. Several activities were involved such as stratigraphy and facies analysis of the continental deposits, geomorphological and tectonic field surveys supported by a fine-scale LIDAR DTM of the area, but also paleontological analyses (freshwater molluscs and ostracods; large mammal), geochronological dating (OSL; ^{14}C), well-logs and geophysical data interpretation (seismic reflection profile; microtremor) (Nocentini, 2016).

Our field and lab results allowed to define seven synthems characterizing the Plio-Quaternary evolution of the ASB partly matching stratigraphic units or synthems already described in previous studies (Centamore & Dramis, 2010). According to our data slope-derived breccias, debris-flow deposits and alluvial clayey-sandy conglomerates characterized the first phase of basin filling (*Colle Cantaro-Cave Fm.*), has highlighted by boreholes and seismic profile interpretation. This Plio-Lower Pleistocene phase was followed by the development of a fluvial environment with floodplains and extensive swamp areas close to meandering fluvial channels (*Madonna della Stada Synthem*) during the Calabrian. After these two major phases of basin filling, the ASB was affected by five shorter tectono-sedimentary events that gave rise to the formation of Middle and Upper Pleistocene synthems, with the younger carved into the previous ones or even into the Meso-Cenozoic bedrock.

This new stratigraphy has been synthetized in the presented fine-scale geological map in which the Plio-Quaternary synthems and the active normal faults of the ASB are emphasised.

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Stratigraphy of upper Quaternary shallow-water contourite drifts and paleoceanographic modeling of the Gulf of Taranto (Ionian Sea, Southern Italy)

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Keywords: Shallow-water contourite drifts, bottom currents, Gulf of Taranto, sea level change, Coastal Modeling.

Shallow-water contourite drifts are sediments deposited in the water depth range where bottom currents may reflect not only basin-scale thermohaline circulation but also local processes that can be controlled by sea-level changes and morpho-bathymetry. We investigate these processes in the Gulf of Taranto (Ionian Sea) by integrating high-resolution reflection seismics, morpho-bathymetry data, and gravity core data with Coastal Modeling System Wave and CMS-M2D numerical models. Both geophysical-geological data and numerical modeling coherently indicate that Latest Quaternary shallow-water contourite drifts formed in the NW sector of the gulf in response to the eustatic fall of the sea-level that induced a severe impact on the bottom current system. The sea level drop caused subaerial exposure of the summit of the Amendolara Ridge that formed an island off the eastern coasts of Calabria and also created a narrow passageway between the island themselves and the northern Calabria coastline. Stratigraphic data indicate that the contourite drifts are bounded at the bottom and at the top by two major unconformities, and show that the sediments drifts formed between the onset of the last interglacial and the Early Holocene (~ 11.500 years BP). The analysis of the stratal architecture allows for the recognition of various contourite facies assemblages, depending on the local sea floor morphology, bottom currents and water depth. These are mostly represented by: a) Drift complex, along incision to the NE of the Amendolara Bank; b) Sheeted drifts, along the northeastern slope of the Amendolara Bank; c) Elongate drift along the northern Calabria continental shelf and upper slope. Numerical models predict that during the LGM the wave induced currents flow is driven roughly parallel to the northern Calabria paleo-coastline and counterclockwise around the north-eastern flank of the Amendolara Bank. The wave-induced hydrodynamics reaches the maximum velocity of ~ 0.1 m/s. According to Shields diagram, the minimum value of the flow velocity which allows the sediments to be mobilized is approximately 0.8 m/s for the considered grain sizes. Therefore, the additional contribution of the wave-induced hydrodynamics at the basin-scale thermohaline circulation of low Adriatic and Ionian created favorable conditions for the occurrence of the contourite drifts. Local erosional features coupled with a substantial lack of contourite deposits is also observed, until the present-day, on the south-eastern flank of the Amendolara Bank, where the LIW flows from the central Ionian Sea towards the Gulf of Taranto.

Stratigraphic architecture of the Campania Plain, southern Italy. A key to understand evolution and impact of volcanic activity

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Keywords: Campania Plain, Southern Italy, Late Quaternary stratigraphic architecture, geographic information.

Purpose of the study is to illustrate an integrated approach to the analysis of a region whose Late Quaternary stratigraphic architecture has been deeply influenced by the volcanic activity. Field surveys and stratigraphic reconstructions furnished new insights to the knowledge of this complex depositional setting.

For its important volcanic activity the Campania Plain, a wide flat area extended between Naples and Caserta, and delimited by the Apennine foothills toward north, east and south, and by Tyrrenian sea, toward west, has been identified as "Campanian Volcanic Zone (CVZ). Considering the CVZ as a regional tectonic depression, many authors believe that many voluminous pyroclastic flow eruptions were vented directly from Apennine sedimentary fault graben, the last being the 39 ky Campania Grey Tuff (CGT), an eruption of 200 km^3. The pyroclastic flow deposits of the CGT blanketed the whole area filling morphological depressions and dipping gently towards the central region of the Plain. These deposits are characterized by different lithofacies that can be recognized within this unit from the base of Apennine foothills to the Plain, mostly derived by the different mineralogic composition in turns related to secondary processes that locally promoted a glass-to-zeolite and analcime/feldespar tranformation.

A geological characterization of subsoil derived from the study of a dataset including about 1000 lithostratigraphic logs from boreholes reaching the depth of 10-to-150 m b.g.l. coupled with field surveys. The study was based on geological, geomechanical, pedological and hydrogeological data, managed into a GIS environment to reconstruct a 3D geological model.

Main results of the study are listed below:

1) The study has permitted to reconstruct the upper surface of the GCT in the whole Plain and recognize a deep downcutting in correspondence of the modern Volturno river course, interpreted as an incised valley originated as a response to the Last Glacial Maximum sea-level drop. This unit represents the first substrate for the Holocene and recent sedimentation.

2) The different lithofacies that characterize the CGT have been described as stratigraphic units. These units have been divided in relation to genesis and lithology according to the CARG (CARtografia Geologica Project for realisation of the new Geological Map of Italy at 1:50,000 scale). The geological data processing has been performed into a GIS environment to develop a 3D geological model. Data have been graphically restored with use of Rockworks 2006 to obtain bi- and tridimensional models of the stratigraphic units, and display the spatial variations and the relationships between different lithofacies. In particular, specific insights have been delineated on the volcaniclastic lithofacies heteropies of CGT across the entire area of study, also considering the contribution of pedogenesis on the reconstruction of the stratigraphic setting.

3) The detailed recognition of the CGT lithofacies in the subsoil suggested new insights in the processes responsible for the volcanic sequence settling.

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A multidisciplinary study of the Homo-bearing Aalat pedostratigraphic succession, Dandiero Basin, East Africa: insights into Pleistocene soil development and paleoenvironmental changes

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Keywords: East Africa, Paleopedology, Sedimentology, Chronostratigraphy, Soil formation, Pleistocene paleoenvironments.

Deep marine cores and Homo-bearing continental stratigraphic records in East Africa revealed relevant paleo-climatic and -environmental changes during the Pleistocene, that are considered among major causes of faunal dispersal and human evolution. Nonetheless, the continental record is often poor because of stratigraphic (and chronological) discontinuities or relatively small extension. Our work focused on a multidisciplinary study of the Aalat section, an Early to Middle Pleistocene sedimentary succession in the Dandiero Basin tectonic depression (Eritrean Danakil, East African Rift System), which represents an exceptional continental stratigraphy including human remains of Homo erectus/ergaster and abundant fossil vertebrates in this area. The study section was characterized from a sedimentological, pedological, magnetostratigraphic, paleontological and volcanological point of view, integrating different field and laboratory analyses aimed at reconstructing the East African Early-Middle Pleistocene transition. The 300 m thick section showed repeated shifts from fluvial to deltaic and lacustrine depositional environments, controlled by local tectonic activity and climate changes. Two main fossiliferous layers were detected in the lower part of the section. Terrestrial vertebrate faunas include a typical Early to Middle Pleistocene East African mammalian assemblage, dominated by taxa with strong water dependence. The ichthyofauna is consistent with the shallow water fluvio-lacustrine paleobiotopes. High-resolution paleomagnetic data vertebrate paleontology and tephrostratigraphic correlations of three tephra layers identified at the top and the bottom of the section, allowed to substantiate the chronostratigraphic frame of the Aalat section, ranging between the Jaramillo event (ca. 1.07-0.99 Ma) and the Matuyama–Brunhes magnetic field reversal (ca. 0.78 Ma). Based on these time constraints, about 1 mm/a rates of vertical aggradation can be estimated, coherently with a poor to moderate degree of soil development and evidence of soil truncation by erosion. Representative soils were described in the field and sampled for physico-chemical, mineralogical, geochemical and micropedological analyses. The main weathering and pedogenetic features consist of pedogenic structure, accumulation of secondary carbonate into calcic and petrocalcic horizons, local iron-oxide/hydroxide staining or matrix rubification. The complex patterns of secondary carbonate features and Fe oxyhydroxides at different stratigaphic heights indicate phases of geomorphic stability alternated to phases of non-deposition and suggest cyclical shifts from arid to humid paleoenvironments during the Early-Middle Pleistocene transition in East Africa.

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Process observation, strata formation and Quaternary "seascape" evolution in coastal to deep-water environments

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Keywords: Anthropogenic deltas, glacial-time deltas, advective sediment dispersal, dense shelf water.

Marine geological studies of Quaternary environments are crucial as they provide the possibility to: link our quantitative observations of modern processes to the generation of strata and interrelated discontinuities; improve our understanding of abrupt climate change, particularly through the best resolved Quaternary records, and, based on that, propose science-based scenarios for our Planet in the near future and under variable amounts of human emissions and global warming; and, study how humans have been increasingly impacting coastal and marine environments in a substantial lack of awareness and exacerbating the possible impact of natural events on coastal population, economy and infrastructures. Based on recent studies at ISMAR, supported by the RITMARE Flagship project, three examples for the above points are discussed. 1) Dense shelf-water formation and its cascading across the slope is a crucial process for exporting Carbon to, and ventilating the, abyss worldwide; this process plays a key role also in the Mediterranean, where it is triggered by the winter cooling of the northern continental shelves: Gulf of Lions, Northern Adriatic and Northern Aegean; the newly formed dense water impact the continental slopes of the three areas pervasively modifying the submarine landscape inherited by the last glacial times. The recognition and quantification of the process of dense shelf water cascading on modern slopes can provide hints to readdress hypotheses on the sediment routing in the ancient geological record. 2) The sedimentary response to abrupt climate change is exceptionally documented by the super-expanded stratigraphic record of the Po low stand delta formed during the last glacial maximum; in this setting, climate-driven fluctuations of sediment flux are recorded by successive shelf-edge low-stand deltas; this setting records the impact of pervasive millennial-scale fluctuations of fluvial-derived sediment supply on the formation of clinostratified deposits (clinothems) that are up to 150m thick and build 40 km across shelf in as little as one millennium. Stable-isotope and quantitative foraminifera analyses reveal two groups of delta units, both advancing in "pulses": deltas characterised by a descending roll-over point trajectories are accompanied by hyperpycnal flows and sand bypass to the slope (accompanied by slope channels and sand lobes) while delta progradation with ascending trajectories reflect homopycnal discharges with most of the sand remaining sequestered in coastal plain settings. 3) The impact of humans on modern deltas is documented worldwide. In the northern Mediterranean, deltas have grown in two major pulses when human-driven deforestation and associated changes in land use brought to a substantial increase in rivers' sediment load; human impact during these two phases overshadowed natural climate change as the first phase of delta growth occurred during a warm climatic interval (the Roman period) and the second during a cold climatic interval (the Little Ice Age). Interestingly, part of the problems of coastal erosion and delta retreat that we observe today are a consequence of the rapid man-induced growth these two intervals of supply-dominated delta growth generating apparatuses that are more difficult to maintain than the wave-dominated cuspate deltas.

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Preliminary results of OSL age dating of late Pleistocene marine terraced deposits of the Metaponto area (Taranto Gulf, Southern Italy)

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Keywords: Middle-late Quaternary, depoositional marine terraces, Taranto Gulf, OSL.

The hinterland of the Taranto Gulf (southern Italy), back to the Metaponto coastal area, hosts a flight of depositional marine terraces developed during Middle and Late Pleistocene. Their effective number and detailed chronostratigraphy are still largely debated, and different interpretations led Authors to suggest different regional uplift-rates related to different geodynamic behaviour.

Aim of this work is to present age date of samples collected in depositional marine terraces located in the area between the Basento and Cavone rivers. Here, recent lithostratigraphic and sedimentologic studies show a complex evolution of successions below each terraced surface and suggest that depositional marine terraces correspond to fourth-order sequences recording high-frequency sea-level fluctuations. The top of the oldest studied succession is 120 m above the present sea level (apsl) and referred to MIS9. The youngest and lowermost one, referred to the MIS1, is the present-day Metaponto Coastal Plain, whose inner edge is about 10 m apsl.

Samples have been collected in beach-upper shoreface deposits, referred, according to sequence-stratigraphy but without absolute age constraints, to substages of the MIS7 and MIS5. Sampled sediments should have been sufficiently sunlight exposed during littoral exposition to be well-bleached and, therefore, Optically Stimulated Luminescence (OSL) datable. Samples were collected on homogeneous sandy (grain-size 120 to 200 µm) layers with opaque cylinders (6 cm diameter) at least 20 cm thick. A single aliquot regenerative (SAR) protocol was used for Dose Rate (De) measurements. De calculations are based on high-resolution gamma spectrometry to give natural radionuclide concentrations. Correction for cosmic rays contributions at the final dose rate was calculated as well.

Three samples were collected in the same locality and at the same stratigraphic level in upper shoreface facies about 6m below the terrace surface in a succession related to the MIS 5 and whose top reaches 41 m apsl. Two of these samples gave a minimum age of 104±5 ky, and 100±6 ky because quartz was saturated. One gave a reliable age of 110±6 ky. These ages suggest that sampled sediments deposited before the MIS 5.3, probably in a time span between the MIS 5.5 and the MIS 5.4 (110±6 ky), confirming the age suggested through a sequence-stratigraphic approach.

Two more samples were collected in deposits located in uppermost positions respect to the previous depositional terrace; therefore these samples should show older ages. For both samples quartz was saturated, and samples have given a minimum age of 100±6 ky and 155±8 ky. This last age suggests that sampled sediments, collected in upper shoreface facies, about 5 m below the terrace surface in a succession related to the MIS 7 and whose top reaches 75 m apsl, were buried before (or at lest during) the MIS 6 (in agreement with the sequence stratigraphic age attribution).

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The late Quaternary uplift of the Crotone Basin, southern Italy

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Keywords: Regional uplift, Crotone Basin, Marine terrace, Glacio-eustasy, Marine Isotope Stage.

The late Quaternary history of the Crotone Basin, located on the Ionian side of Calabria, southern Italy, was characterized by overall uplift conditions that persist today. The transition from subsidence to uplift occurred close to Marine Isotope Stage (MIS) 11 (ca. 0.4 Ma), which is recorded in the sediments of an emerged submarine canyon fill (Zecchin et al., 2011a). The subsequent progressive emergence of the area was punctuated by several marine transgressions linked to high-frequency, high-magnitude glacio-eustatic changes, which are recorded as marine to continental terraces (Gliozzi, 1987; Zecchin et al., 2004, 2009, 2010, 2011b). These high-frequency sequences show a variable stacking pattern due to the interplay between glacio-eustasy, uplift and local physiography. In particular, a progressive SE-ward migration of the shoreline is documented since MIS 11. This trend was enhanced during the MIS 5.5 to MIS 2 time interval, due to the combined effect of uplift and lowering glacio-eustatic sea level until the Last Glacial Maximum. Moreover, the regional uplift also led to a physiographic change from relatively low-gradient to high-gradient settings between MIS 7.1 and MIS 5.5 (Zecchin et al., 2011b). A comparison between the late Quaternary geological record of the Crotone Basin and that of other basins is crucial to improve the present knowledge on past sea level related to MISs. This ultimately helps to better understand the Holocene sea-level history and the human contribution to sea-level change, in order to predict future scenarios.

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Reconstruction of the geological evolution and stratigraphic architecture of upper Quaternary continental deposits through field and boreholes data: the case of the lower basin of the Chienti River (Marche)

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Keywords: Stratigraphic architecture, Continental deposits, Late Quaternary, Chienti River, Marche Region.

The reconstruction of upper Quaternary stratigraphic architecture along present coastal and river plains is instrumental for resource management and hazard reduction, including estimate of water resources, defence from salt intrusion and reliable prediction of pollutant dispersal pathways. To this aim, this paper integrates outcrop and subsurface data to present a high-resolution study of the stratigraphic architecture of the late Quaternary continental sediments within the terminal portion of the Chienti River valley.

The study area, located in the external sector of the Marche Region, roughly between the villages of Morrovalle and Villa San Filippo, is characterized by two major hydrographic catchments related to the Chienti River and one of its tributaries, the Ete Morto River.

In order to reconstruct the geological and stratigraphic evolution of terminal portion of the Chienti river, two main datasets have been used: the 1:50,000 scale 303-Macerata and 304-Civitanova Marche geological Sheets (ISPRA 2009, 2011) and an exceptionally high amount of subsurface data, consisting of 527 boreholes provided by ARPA-Marche.

The geological maps were verified on the field, particularly along the boundary between the two sheets, and were digitalized by ESRI ArcGIS ArcInfo 9.1, whereas the stratigraphy beneath the present Chienti alluvial plain was reconstructed along five transects transverse to the valley direction (maximum length about 6 km). Cross-sections highlighted the occurrence of a flight of Late Quaternary alluvial terraces incised into the Lower Pleistocene bedrock (alternations of prevailing pelitic terrains and arenaceous layers) and resulting from at least four episodes of valley incision and infilling, probably triggered by the interplay regional tectonic uplift and glacio-eustatic sea-level fluctuations.

The first- and second order terraces are suspended and usually separated by substrate exposures, whereas the third and fourth-order terraces are in continuity and consist of amalgamated fluvial-channel gravels and floodplain silts and clays. The older terraces are tilted more than the younger ones and the basal surface of the fourth-order terrace, the best preserved of all, displays the typical concave-up morphology with some anomalies near the confluence of the Ete Morto in the Chienti River (E-E' section), where a 10 m high threshold occurs.

ISPRA 2009, 2011. http://sgi.isprambiente.it/geoportal/catalog/main/home.page

SESSION S13

Coastal changes, from past records to future trends: proxy analysis, modelling and monitoring

CONVENERS AND CHAIRPERSONS

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Historical evolution of Volturno coastal plain and current shoreline trend as tools for territorial management

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Keywords: Historical analysis, costal trend, natural hazards, costal management.

The Volturno coastal Plain (VP), laying from Mondragone town and Lago Patria (Southern Italy), was intensely modified by antrophic activities mainly in the last centuries; crops and urban zones took the place of natural lands. The urban sprawl as the events associated to the global warming and local climate deteriorations (relative sea level rise, storm surges, river flood) are the main causes of coastal erosion.

During the last 3-4 ka, VP has experienced an increase in sedimentary input, a substantial slowdown of sea level rise rhythms and a progressive seaward shift of coastline and barrier-dunes-lagoon systems. In particular, the delta system development and the strongest coastal progradation phase (about 2 km) started from Roman period (ca. 2.5 ka B.P.) and reached the apex between c.a.1500-1800 A.D. coinciding with the period called Little Ice Age.

From historical maps, aerial photographs, topographic maps and satellite images covering the 1817-2012 time span, 10 shorelines were delineated. Along 165 transects spaced 200 m apart, the shoreline variations and the trends were assessed; the first was calculated for each pair of two consecutive shorelines, while the latter by using all the shorelines available for the 1957-1997 and 1997-2012 time windows.

In the first time window, both sides of Volturno river mouth and the Ischitella locality were in erosion. At the beginning '60s, the Volturno coastal zone was deeply modified by the antrophic pressure, 4 rivers cross-sections and 10 dams were built in the Volturno basin. Moreover, since the '70s, the urban environment expanded rapidly and the construction of seaside tourist center Pinetamare took place. In order to preserve the beaches and the houses very close to the shoreline, several coastal defences were also built from 1978 to 1979 nevertheless they stabilized the Pinetamare zone but increased the erosion in Ischitella locality.

In the 1997-2012 period, moving from Lago Patria toward Mondragone city, a first coastal sector was in erosion (-1.4 m/year), the area of Pineta Mare was characterized by stability (0.6 m/y), northward an accretion rate of 2m/year was recorded. At Volturno river, the left side was in erosion (mean value = -2 m/y) while the right side in accretion (mean value = 1.4 m/y). Still moving northward, there are other two sectors, the first was characterized by a rate of -2m/year and the last by a rate of 1m/year. At present, the coastal defences do not work well, they are for the greatest part under seawater; this condition favor the establishment of sectors in erosion alternate with those in accretion.

The knowledge of both historical evolution and of present day shoreline trend at VP can be considered a vital tool to support the development of a coastal system able to adapt and cope with natural hazard and to improve its naturalness.

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Multidisciplinary approach to reconstruct flooding scenario along the subsiding coast of Lipari Island

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Keywords: multibeam bathymetry, photogrammetric surveys, relative sea level change, submerged Roman pier.

Lipari is the largest and most populated island of the active Aeolian volcanic archipelago (Southern Tyrrhenian sea). In this study we show and discuss data on the relative sea level change inferred from historical and archaeological indicators located along the eastern coast of Lipari.

In particular we focus on a~200x60 m of size submerged pier of Roman age dated at 2000±100 years BP, located at Marina Lunga, that correspond to the location of the modern harbor of Lipari. This structure is a valuable indicator of relative sea level change and vertical land movements, being presently located between 9 and 13 m below sea level. Global Positioning System (GPS) data collected in the last 18 years also suggest that land subsidence is still continuing in this region. From our investigations, a mean subsidence rate exceeding~6±0.3 mm/yr^{-1} is estimated, with a volcano-tectonic contribution of~5±0.3 mm/yr^{-1} for the last 2 ka BP, as inferred from the comparison against the latest sea level prediction for the Southern Tyrrhenian Sea. Based on *i)* Digital Terrain and Marine Models realized through the merging of ultra-high resolution multibeam data and aerial photogrammetric surveys realized using Unmanned Aerial Vehicles, *ii)* current rates of land subsidence estimated both from 18 years of GPS data, *iii)* the submerged roman pier and flooded buildings built during the last three centuries and *iv)* current and IPCC predicted rates of sea level rise, a flooding scenario is provided for the year 2100.

The upper and lower limiting values of relative sea level rise are estimated at 1.68 m and 1.21 m, for the maximum and minimum climate change scenarios, respectively. Here we show the expected impact of marine flooding at Lipari for the next 85 years and discuss the hazard implications for the population living along the shore.

Coastal erosion and inundation assessment along the Ionian coast of Basilicata, southern Italy

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Keywords: Coastal erosion, coastal inundation, natural and cultural heritage vulnerability, Basilicata.

Coastal hazard management includes the assessment of the physical conditions controlling the response of natural and anthropized coastal sectors to environmental perturbations, such as storm surge and extreme river discharges. In the present abstract are presented the results of a geomorphological analysis of a wide sector of the coastal areas of the Basilicata, southern Italy, where strong human impact and environmental factors have promoted the occurrence of shoreline retreat and coastal erosion. Two coastal susceptibility indexes, i.e. the Coastal Erosion Index (CEI) and the Coastal Inundation Index (CII), have been adopted to analysed recent trends of coastal evolution in the littoral confined between the mouths of Bradano and Sinni rivers. Assuming that a good index should be based on a minimum amount of information already available or easy to be obtained (Cooper &d McLaughlin, 1998) each of the proposed indexes is a linear combination of weighted variables covering geomorphological, physical, and anthropogenic aspects. Each variable is ranked in five classes ranging from 1 (null/very low susceptibility) to 5 (very high susceptibility) and overlapped on a GIS platform through a logical overlay operation (Rangel & Anfuso, 2015). This approach is a very useful tool for hazard and risk analysis studies. Preliminary results show that the methodology allows identifying stretches with different degree of susceptibility to erosion and inundation. Moreover, such a methodology is profitable as it requires parameters obtained through interpretation of easily-available aerial-photo/orthophoto and wave and run-up data. It is also easy to apply without detailed field surveys. Results highlight that the northernmost sector of the study area is affected by strong erosion rates in the last years whereas the areas surrounding the river mouths are more exposed to flooding phenomena. Due to the occurrence of touristic infrastructures, natural protected areas, and archaeological sites of high value, the study area can be considered an area strongly vulnerable to marine erosion, river flooding, and marine inundation events.

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Landscape changes along the coasts of Naples Gulf since the Roman times, inferred from new geoarchaeological data

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Keywords: Historical landscape changes; submerged geoarchaeological sites; archaeological sea-level marker.

The coasts of the Gulf of Naples has been affected by significant changes since the Roman period that can be ascribed to several factors. These coastal changes have depended not only by vertical ground movements and by the eustatic sea-level rise but, in this case, also by the effects of Plinian Vesuvius eruption of 79 AD that particularly influenced the coasts stretching from Portici to Castellammare di Stabiae and some pocket beaches of Sorrento Peninsula (Mattei, 2016 and references therein).

During the I a.C., the Vesuvian coast suffered a subsidence by the effects of a vertical ground movement just before the eruption of AD 79 that flooded the coasts of Herculaneum and Torre del Greco. Afterwards, the Vesuvius 79 AD eruption produced an instant progradation of hundreds meters due to the emplacement of powerful pyroclastic density currents (PDC), up to 20 m thick in Herculaneum. This progradation was rapidly eroded by waves bringing the coast in the pre-eruption position between the Torre del Greco and Torre Annunziata, and dismantling only a part of coastal progradation at Herculaneum.

The nearest Sarno plain during the I a.C. presents a sea level to about -4 m b.s.l., and a coast 1 km retreated. Here the Vesuvius eruption produced a slow and progressive coastal advance about of 1 km in front of ancient Pompeii, diluted in the two millennia, overwhelming the subsidence occurring at a mean rate of 1.5 mm/y.

Along the Sorrento Peninsula coasts a sea level rise about 1 m, produced a modest retreat due only to the submersion along the limestone sea cliffs (Capo di Sorrento and Punta Campanella sites), while the tufa cliff suffered also an erosional retreating (Sorrento Marina Grande site). In this sector, the eruption of 79 AD had little influence with its primary products (no more then 1 m of pomiceous fallout and thin silty layers surge) only at the mouth of short streams, while the subsequent debris and hiperconcentraded flow, descending in the followed decades, produced coastline progradation more than 200 m, totally dismantled by 3 centuries (Seiano site).

In the opposite side of the Gulf, the rocky tufa coast of Posillipo (western sector of Naples) and also the adjacent low coast of Chiaia and Municipio (central-eastern sector of Naples) in the last 2 kys have suffered the effects of a subsidence comparable to that of Naples Gulf, as demonstrated by a I a.C. sea level at -3 m b.s.l. However, while the Posillipo coast is in retreat the Chiaia coastal plain and the area of Greek –roman port is in progradation 100 -200 m mostly because sedimentary inputs coming form the hillslopes, probably favoured by antrophic impact.

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Monitoring and mitigating the coastal vulnerability in Southern Italy

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Keywords: Sele River Coastal Plain, Wave run-up, Beach retreat.

Coastal vulnerability and risk monitoring is an important tool used by public administration for defining relevant actions and interventions of mitigation in critical coastal areas.

To this aim, this paper describes a vulnerability and risk index developed by hydraulic engineers and geologists (Di Paola et. al., 2013) for determining a possible prioritization of the interventions in coastal areas. The methodology was applied to a case study in Southern Thyrrenian coast, while the methodology of mitigating the coastal vulnerability was applied to a case study on the Jonian coast.

The coastal vulnerability assessment index (CVA) relies upon three indicators: run-up distance (as a measurement of coastal inundation), beach retreat (as a measurement of potential erosion), and beach erosion rate (obtained through the shoreline positions in different periods).

The risk evaluation relies upon the exposure and damage assessment, which uses land cover data and a statistical population dataset, and has been validated with a conceptual framework based on the observed damage ranking related to the tested coastal areas (Benassai et al., 2014).

The coastal vulnerability mitigation relies upon the updating of the CVA through the Backshore Coastal Protection Structure Index, which is based on the transmission coefficient that accounts explicitly for the efficiency of defense works in mitigating inundation and erosion by wave storms.

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Evolution of a volcanoclastic coastal cliff affected by weather-marine factors: Terrestrial Laser Scanning (TLS) technique at Campi Flegrei caldera rim

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Keywords: Terrestrial Laser Scanner, Monitoring, Coastal cliffs.

The Coroglio coastal cliff has an elevation of 150m a.s.l. and a breadth of at least 200m. It is located on the eastern of the Campi Flegrei caldera rim of Neapolitan Yellow Tuff (NYT). Its geomorphological evolution may be due to structural setting, lithology and weather-marine factors. The cliff consists mainly of an extremely lithified tuff, associated to the eruption of NYT about 15 Ka (Deino et al. 2004), overlaid by more recent products of the Campi Flegrei volcanic activity.

Terrestrial Laser Scanning (TLS) technique is used for environmental monitoring and the study of unstable rocks (Abellán et al. 2011) with purposes through the creation of high resolution Digital Surface Model (DSM). This method allows the reconstruction, by means of a dense cloud of points, of a 3D model for the entire investigated area. In our study we used a long-range laser scanner model RIEGL VZ1000®. Various surveys (April 2013, June 2014, March 2015, February 2015) have been performed for monitoring coastal cliff morphological evolution (Caputo et al. 2016; Matano et al 2016).

The aim of the multi-temporal monitoring has been to estimate the evolution of coastal cliff through the comparison of DSMs in GIS environment. The comparison have evidenced interesting geomorphological processes that act on the cliff mainly due to weather-marine factors.

In particular it was observed a very intense local retreat of about 8m at the base of the cliff, where there is soft rock, with an erosion rate of the 2200m^3 and an area of the 830m^2. This latter is mainly due to the sea wave action. In other part of the sector cliff it was observed a widespread small erosion associated at the less compact lithology with an erosion of 250m^3 on an area of 200m^2 overall. Finally, the upper part of the cliff shows a loose of pyroclastic deposits covered by very thin thickness vegetation with a volume of 142m^3 on an area of 144m^2.

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A review of geological hazard records in Quaternary uplifted terraces, central coast of Ecuador

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Keywords: tsunami deposit, ash-fall deposits, Quaternary marine terraces, coastal Ecuador.

Geomorphic and stratigraphic studies and radiometric dating techniques applied to Quaternary sedimentary sequences located on the Jaramijo site (Ecuador's central coast, South America), have allowed the recognized upper Pleistocene to Holocene uplifted terraces. The marine terraces, from bottom to the top, are: T1 at an altitude of 20 meters a.s.l. (above sea level) (dated 1190 ± 30 BP to 1030 ± 30 years BP), T2 terrace at 30 meters a.s.l. (43.245 ± 460 years B.P.) and T3 at an altitude between 43 to 57 meters a.s.l. (ca. 120.000 years). The T3 terrace was previously recognized by Pedoja et al. (2006), but our research outlined two new terraces (here named T1 and T2) mostly covered by volcanic-ash deposits. This paleogeographic reconstruction is linked with the continental margin active tectonic and MIS1 to MIS 3 (Marine Isotope Stages) glacial and interglacial stages. EJ-02 sample is referred to theT2 terrace, the EJ-02E lithologic unit is composed by medium sand with plentiful bivalve molluscs indicating a sublittoral zone, where sediments probably were deposited in a water column from 0 to 30 meters deep. The radiocarbon age of this unit is 41.295 to 40.140 years BC (cal. 43.245 to 42.090 years BP). The δ 18O and -1 to -1.5 o/oo values can be associated with a short interstadial stage within the glacial period MIS 3, associated to a rapid sea level rise reached -10 to -20 m bellow of current level. EJ-01 and EJ-03 geological sampling stations were located on the T1 terrace. The main geomorphologic features of this terrace are a wave-cut beach platform permanently exposed at the lowest tides and an 18 m-high coastal cliff retreating ca. 1.5 to 2.5 meters/year (Chunga et al., 2015). T1 terrace is composed by Late Holocene sequences of sand and clay sediments intercalated with loose to weakly consolidated volcanic-ash layers. One of the most remarkable geoarchaeological findings in this outcrop (EJ-01E sample) were human bones related with Manteña culture integration period, within a 8 to 25 cm-thick volcanic ash layer (Mulas et al., 2015) (radiocarbon dating of 1.190 ± 30 B.P.). The EJ-01D unit is one of the most important sedimentary levels that provide tsunami hazard information. This layer presents an upper and lower erosive contacts and chaotic deposition of medium to fine-grained sand. Inside the matrix are present Melonis sphaerodis foraminifera of bathyal environment, indicating a possible tsunami deposit with 6.3 meters a.s.l. run-up height (estimated age of ca. 1.200 ± 30 B.P.). All of these stratigraphic and palaeoseismologic features will allow us to understand the catastrophic series of geological events that abruptly shaped the landscape (such as subduction earthquakes, local tsunami, and volcanic lahar-ash landslides). The Jaramijo site tectonic uplift rate (ca. 0.5 to 0.98 mm/year) allows to preserve the well formed marine terraces outcropping in central coast of Ecuador.

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Interplay between sea level rise and tectonics in the Holocene evolution of the Sant'Eufemia plain (Calabria)

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Keywords: Microplaeontology, pollen, sediments.

The western Calabria region is characterized by high relief rocky coasts alternating with large plains, such as the St Eufemia plain. The Holocene history of this plain has been reconstructed by integrating morphostratigraphic, chrono-stratigraphic and palaeoenvironmental analyses. A new core, 20-m long, drilled in the modern plain and chronologically constrained through ten ^{14}C datings, proved to cover the last 9500 years. Micropaleontological and sedimentological analyses, coupled with palynological investigation, allowed the evolution of the environments to be reconstructed in detail.

During the early Holocene, an open lagoon established along the coast over the alluvial environment left by the late Pleistocene sea level low stand. At ca. 8600 yr BP the growth of barrier ridges drove the development of marshy areas, bounded at their back by a Pleistocene marine terrace +30/40 m high. Humid conditions, with small lakes and wetlands, persisted in the narrow coastal plain along the middle-late Holocene. Between 2500 and 1500 yr BP, the increase in the alluvial and littoral sedimentation triggered the final phase of coastline progradation. Comparison between the sedimentary evolution of the St Eufemia plain and the Holocene sea-level rise history sheds lights on the tectonic behavior of this coastal sector which seems to have experienced a more intense uplift in the early Holocene and a tendency to stability in the middle-late Holocene.

Innovative Monitoring of Coastal and Marine Environment – The MONICA project

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Keywords: monitoring, coastal evolution, marine environment, multi-hazard, Campi Flegrei.

The MONICA (Innovative Monitoring of Coastal and Marine Environment) project aimed to give a major contribution to prevention and management of marine and coastal environmental emergencies.

The project afforded multidisciplinary aspects related to the study of short-term evolution and monitoring of coastal and marine areas in sectors characterized by active volcano-tectonic processes, also involving significant vertical ground deformations, such as the Campi Flegrei and the Pozzuoli Gulf (Italy). The MONICA project aims to effectively contribute to the prevention and management of such environmental hazards, through the design and implementation of innovative monitoring systems.

The target of the prototype monitoring systems developed in the framework of this project is the Bay of Pozzuoli, which is the submerged part of the Campi Flegrei caldera. It is a large volcano-tectonic structure, marked by two caldera-forming eruptions occurred 39.000 (Campanianian Ignimbrite) and 15.000 (Neapolitan Yellow Tuff) years ago. The last eruption occurred in 1538 AD. The area has been repeatedly affected by large ground movements, on the order of tens of meters on the secular scale. Ground uplifts are generally accompanied by intense seismicity, normally occurring in swarms, with magnitude up to 4. This area, densely populated and for a large part including the city of Naples, is also characterized by coastal landslides, so representing a typical multi-hazard target.

This work presents the innovative monitoring system designed and installed by the MONICA Project. It consists of a ‘Coastal’ segment aimed to monitor the landslide movements and precursors, using various technologies, and of a ‘Marine’ segment, based on a fiber optic cable installed 1 m below the sea bottom in the Gulf of Pozzuoli, for a total length of 2.5 km; along the cable, 4 groups of sensors are installed.

The systems so far developed and demonstrated in this high risk multi-hazard area can be conveniently used in other areas, not only characterized by natural risks. In fact, the concept of the Marine monitoring segment can be very useful for monitoring pollution, ground deformation and seismic effects around the off-shore oil and industrial platforms.

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Ancient settlement dynamics and predictive archaeological models for the Metapontum coastal area in Basilicata, southern Italy: from geomorphological survey to spatial analysis

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Keywords: Coastal environment, spatial analysis, predictive models, southern Italy.

Geomorphological mapping, GIS-supported statistics, and analysis of the topographic features of the landforms have been investigated and combined to extract the settlement rules and the site dynamics of the Ionian sector of Basilicata, southern Italy, which roughly coincides with the ancient territory of the Greek settlement of Metapontum and its *chora*. Analyses of environmental dynamics, spatial and temporal evolution of settlements and, more in general, of the relationships between man and landscape have been carried through an integrated approach that, starting from a detailed geomorphological analysis, tried to extract the spatial relationships between archaeological site locations and landform/landscape features. We have used spatial analysis to study relationships between environmental parameters and archaeological sites by developing an analysis protocol that could reveal including and excluding factors, useful for the research and the discovery of new archaeological sites. Consequently, a model that considers interactions between sites and some parameters such as the elevation, the slope, the aspect, the landforms, the land use and the distances from water was constructed. Moreover a final sensibility map was produced, that wants to help the archaeologist to know, in every point in the space, how many and which are parameters that could increase the probability to find new archaeological sites and that are survey priorities on the study region. The layout of the site arrangement clearly traces the main geomorphological features of the area (i.e. settlements along fluvial scarps, sites on the flat surfaces of marine and fluvial terraces, main villages in the coastal plain). From classical to Hellenistic time span, a significant increase of sites can be observed in both the coastal plain and in the intermediate orders of marine terraces, whose top surfaces range from 45 to 110 m a.s.l.: this could mean that the pre-existing environmental setting of the coastal plain where preserved (i.e. no diffused presence of marshes and swamps) and the plain was not abandoned, but at the same time the terraced surfaces offered similar or better conditions for agricultural practices. From Hellenistic to Roman times, a dramatic collapse of the stable human presence occurred, probably due to historical causes coupled with a landscape deterioration likely linked to an increase in flooding occurrence in the coastal plain and in the floodplains of the lower reaches of the main rivers.

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Erosion risk assessment along the Gran Canaria Island coastline

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Keywords: Coastal Erosion, CVI, CVA, Risk Erosion, Gran Canaria Island.

Permanent or temporary increase in sea level, subsidence and storms threatens many coastal areas with erosion, inundation and episodic flooding. The sandy low beaches of the Gran Canaria Island, where most ecological zones and urbanized areas are concentrated, are subject to a significant risk due to a high environmental hazard with considerable socio-economic implications.

The main goal of this study is to identify and quantify the coastal risk along the Gran Canaria coastline, taking into account the coastal erosion hazard and the socio-economic impact. This evaluation examined the beach retreat due to storm surge, estimated based on both geological-geomorphological data (bathymetry, sedimentology and beach width) and wave climate data. The analysis of morpho-sedimentary beach characteristics, wave climate and multi-temporal series of aerial photographs and topographic maps was carried out.

The coastal hazard evaluation was performed using two levels of analysis: the first one regarding the entire coastal perimeter (CVI method, Gornitz at al., 1997), the second one regarding specific areas, identified due to their location and/or socio-economic importance (CVA method, Di Paola et al., 2014). In the second case, the coastal erosion hazard assessment was done along a number of beach profiles performed on May 2016. Results are given in terms of impact index, obtained by combining the responses to coastal inundation and storm erosion, and the beach erosion rate. The exposure and the damage of the coastal assets (for the socio-economic impact) were evaluated with a simplified conceptual framework which uses land cover data and a statistical population dataset (Benassai et al., 2015).

The analysis of results evidences different coastal responses as a function of the beach width and slope which, in turn, depend on the local land use and anthropization level. In general, Gran Canaria has a very high level of hazard, but only specific areas are characterized by a high level of socio-economic impact due to the presence of urban areas or protected ecological zones. Therefore, the Gran Canaria coastal erosion risk shows different levels, from low to medium at the west coast and high to very high between the municipalities of Arucas and Telde and around Maspalomas (San Bartolom de Tirajana). Obtained results are promising, suggesting that an improved coastal planning may considerably reduce coastal vulnerability by avoiding further/excessive exploitation/development of high risk areas.

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Retreat rates estimation of the Torrefumo coastal cliff, Campi Flegrei volcanic district, Southern Italy

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Keywords: Photogrammetry, LiDAR, change detection, coastal cliff, retreat rate.

Geomorphic evolution of sea cliffs has significant impacts on coastal settlements worldwide, so that evaluation of cliff instability processes, failure factors, and retreat rates involve numerous scientists for risk and coastal management purposes. Aerial photogrammetry and LiDAR (Light Detection And Ranging) are among the most used techniques for topographic characterization of coastal environments. Multi-temporal point clouds and high-resolution Digital Elevation Models (DEMs) derived from these techniques can be used to perform change detection analysis and identify cliff surface modifications through time. Volumetric changes and sediment budgets can be also estimated multiplying the DEM of Difference (DoD) elevation data by the area of the grid cells. A crucial role in the fusion of photogrammetry and LiDAR-derived models is the evaluation of their different spatial accuracy and co-registration, so that a detailed error analysis is required to reach suitable change detection results. In this study, we present results of a change detection analysis performed on the Torrefumo coastal cliff, Campi Flegrei volcanic district, Southern Italy. The analysis was based on DEM comparison and allowed us to estimate the average cliff retreat rates in the time intervals 1956-1974 and 1974-2008. We used historical aerial images acquired by the Military Geographical Institute (IGM) of Italy from the years 1956 and 1974, and a LiDAR survey executed by the Province of Naples on 2008. The images orientation procedures were carried out using ERDAS™ Imagine 2015, while both photogrammetry and LiDAR derived DEMs were produced in ESRI™ ArcGis. In order to compare DEMs and estimate volumetric changes in the considered time intervals we used the Geomorphic Change Detection 6 software (GCD 6 - http://gcd.joewheaton.org/), that works as plug-in within ArcGis. The GCD 6 code allowed us to quantify elevation uncertainty related to each DEM in a spatially variable way using the fuzzy set theory, and to know how it propagates through the DoD. The 1956-1974 and 1974-2008 average retreat rates of the Torrefumo cliff were calculated through the equation proposed by Young and Ashford (2006). Results of the volumetric change detection analysis show higher eroded volumes in the 1956-1974 time interval compared with volumes of the 1974-2008 interval. Volumetric data influence directly the average annual retreat rates related to the two intervals, passing from about 1.2 m/yr to 0.17 m/yr. We observed that such significant variation has been influenced by the presence of a boulder barrier built in the early 80's to protect the cliff toe. Further geomorphic and geological studies, by the use of terrestrial LiDAR and photogrammetry from drone, are being underway to evaluate how retreat processes are still acting.

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A multi-scale and multi-disciplinary approach for the study and monitoring of rocky coastlines

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Keywords: Multi-scale analysis, multi-disciplinary approach, remote sensing, numerical simulation.

Slope instability is one of the main natural hazards which can affect hard rock coastlines. Different failures mechanisms may be possible depending on the influence of the rock mass discrete fracture network and the relative orientation of the coastline: failures may be either discontinuity controlled or dominated by rock mass behaviour. Using the north coast of Cornwall as an example the paper presents a multi-scale and multi-disciplinary approach for study and monitoring of coastal instability. Several cliff failures have occurred in recent decades, indicating the need for further research and monitoring to reduce the risk to both infrastructures and persons.

Analysis of multi-temporal aerial LiDAR data and orthophotos, available through the Channel Coastal Observatory, was undertaken to locate recent landslide failures. Three different LiDAR data sets, acquired from 2008 and 2014, were used to highlight failed areas and their geometry and orthophotos were used for subsequent validation. In addition, terrestrial LiDAR point clouds were also used to identify the structural and geomorphic features that characterize these coasts; special emphasis was given to identification of joint sets, tension cracks and recent landslide headscarps. This information was then integrated with the available geological data to create a GeoDatabase using GIS techniques. This combined dataset was then used to select areas for more detailed (small-scale) study.

These detailed studies included an engineering geological evaluation and use of terrestrial LiDAR and photogrammetric surveys. Data gained from these surveys were used to complement the slope geometry data obtained from aerial LiDAR and to provide further understanding of scale effects (differences between large scale structural studies performed with aerial remote sensing techniques and small scale studies with terrestrial remote sensing techniques).

Finally, integration of data from both large and small scale studies was performed to undertake back analyses of the observed failures. These analyses were performed using a combination of conventional approaches and more sophisticated numerical simulations. The aerial and terrestrial LiDAR data was used to assist generation of numerical models. The geometry of the slope instabilities and the location of the identified (and active) tension cracks were then utilized to calibrate the numerical simulations. The results of these analyses are important to improve our understanding of coastal instability mechanisms and also provide a framework for understanding future coastal recession and factors controlling potential instability.

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The use of innovative monitoring systems for evaluation of rock slope instabilities and coastal dynamic

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Keywords: Coastal dynamic, slope instabilities, geomatics, LiDAR, UAV.

The technological development of the last decades improved the number of possible monitoring systems that can be used for the identification and monitoring of the slope instabilities related to the coastal evolution. Several monitoring systems like SAR and LiDAR are now considered as common tool, which can be used for the control of the effects of geomorphological processes through a multi-temporal analysis.

In addition, the use of geomatics and monitoring systems in the field of coastal evolution also registered an improvement in the last years. These innovative systems are supported by the introduction of new possibilities, like for example, the use of UAVs. Unmanned Aerial vehicles are considered important novelty in geomatics, because coupling with structure from motion (SfM) algorithms, they introduce the possibility for fast and cost limited acquisition of georeferenced ultra-high resolution images of a studied area.

Additionally, SfM algorithms offer innovative possibility for obtaining a digital surface model (DMS) of analyzed area. A solid image can be obtained by combining orthophoto and DSM, which could be considered as a good solution for the study of rock slope instabilities often affecting coastal areas.

However, the use of UAVs may be limited due to several aspects like actual legal restrictions, which allow their application only in some areas, or data processing, which may be difficult due to DSM filtering, often resulting in DTM with less accuracy and resolution than LiDAR. All these systems are now available to identify and monitor the slope instabilities and to study other morphological processes.

One of the most critical aspect of these innovative systems is related to their integration with other systems. The data integration is important for monitoring purposes, where the simultaneous use of different systems aimed to measure several physical parameters, allow the acquisition of a complete dataset, which can be used for numerical modeling setup. In this context, these interesting innovations may lead to the development of smart networks, which probably in the near future, will become the most useful and low cost solution.

Albanian coastline facing the challenges of climate change

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Keywords: coast, climate changes, flood, abrasion, agricultural lands, infrastructure, heritage, tourism.

In global scale, the coastline is under the constant pressure of the concentration of population, buildings and economical activities. Therefore, the exploitation of natural resources has been intensified and has damaged the landscape and environment. This process is occurring when the climate changes are more evident and the level of World Ocean has risen, causing erosion of the coasts, damages of the agriculture lands, infrastructure, settlements, objects of natural and cultural heritage, investments in tourism and other sectors.

Its long coastline of 430 km ranks Albania among the first places in the Mediterranean basin for this indicator. This is an important premise for the development of marine economy, transport, trade and tourism, especially when the coastal areas are valorized more than ever.

The study is focused in an area of 3347.7 km2, where settle 606.370 inhabitants. It includes the territory of all local units in Albanian coast, which are directly or indirectly affected by the climate changes. Albanian coastline has been affected by many negative phenomena such as: the abrasion of sandy lower coast (beaches in the accumulation sectors), which has accelerated the damage of the natural landscapes (sandy dunes, vegetation, fauna etc.); environmental pollution from the industrial, urban and construction wastes; degradation of the landscape from the deforestation and illegal settlements etc.

This paper analyses the impact of climate changes on residents and tourists' health; the threatening factors that might risk life security (floods, fires, microbes and insects carrying infective diseases); reduction and pollution of drinking water, food and fuel reserves, quality of environment and landscape. It also suggests the adaption measurements to face the climate change. The study aims to help residents, investors and decision makers to organize their life and economic activities according to the expected climate changes. In this way, they will move toward social, economic and environmental sustainable development of the coastal area.

Climate change and water risks management at the coastal area of Lezha region, Albania

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Keywords: Water, risks, floods, infrastructure, climate change.

The coastal area of Lezha Region is located 155.2 km North of Shengjini mount, up to the Ishmi river in South and from the national road Tiranë – Lezhë (East) up to the Adriatik Sea (West). It belongs to 3 communes: Shëngjin, Shënkoll and Fushë Kuqe. It has 16 settlements and 33,614 inhabitants.

This geographical location: between Tirana (the capital) and Shkodra (principal centre of North Albania) together with the presence of fertile land and of the sea, the Mediterranean climate and both surface and ground water resources, as well as the rich flora and fauna have encouraged the presence of a dense population and the development of a complex economy, mainly of the primary and tertiary sectors.

Due to the lower streams of three relatively big rivers going through the area (Drini i Lezhës up North, Mati in the centre and Ishmi at South) water related risks have always been a threat.

Floods from rivers and heavy rains have been common until 1965, when works were carried out for the riverbed management, for marshes reclamation and pumping of superfluous water. After 1990, due to damages to protection infrastructure and drainage systems, the flood risk is present again causing (almost every year) property and environmental damages.

Failure to properly manage these risks is mainly caused by lack of funding at the local level. Obviously, the area is in urgent need to solve the problem. Protection infrastructure needs to be rehabilitated along the riverbeds, drainage canals need to be cleaned and deepened, pumping stations need to become operational, etc.

This paper provides new information and awareness on the forms and possibilities for sustainable management of the area in the future.

Methods used comprise site observation and surveys, documents consultation, measurements, mapping, photographing, analysis and synthesis.

Comparison between two present day Sabellariidae biocostructions: *Sabellaria alveolata* (Ostia, Thyrrenian Sea) and *Sabellaria spinulosa* (Torre Mileto, Adriatic Sea) reefs

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Keywords: Sabellaria alveolata, Sabellaria spinulosa, worm tube, reef, Tyrrhenian sea, Adriatic sea.

Sabellaria is a genus that comprises suspension feeders and tube-building epifaunal polychaete worms. These animals are able to build reefs with their tubes made up of sand and shell fragments that are held together with mucous produced by themselves. Among worms, *Sabellaria* is the most important frame-builder of large bioconstructions in temperate marine areas. The Sabellariidae reefs are widespread distributed in the Mediterranean and along the Atlantic coast of Europe, but still their sedimentological aspects are little known. Along the European coast, the largest biogenic reefs are composed by *Sabellaria alveolata* (Linnaeus, 1767); this worm forms large banks that are very common in the intertidal zone. Conversely, *Sabellaria spinulosa* (Leukhart, 1849) is a small, tube-building worm that usually builds small bioconstructions in the subtidal and lower intertidal/sublittoral zone.

In this work, we compare the reefs built by these two different speciesalong different Italian coastal sectors (*Sabellaria alveolata* - Ostia, Thyrrenian Sea; *Sabellaria spinulosa* - Torre Mileto, Adriatic Sea).

Here, we quantitatively describe the morphology of worm tubes and analyse the textural, morphometrical and mineralogical features of the sand grains that are trapped in the two different sites. Similarities and differences have been discussed on the basis of eco-biological features and physical environmental conditions. Finally, the evolution during time of the reefs and the role of *Sabellaria* bioconstructions in the coastal protection have been evaluated.

Coastal morphology, sea level changes and tectonic in the Holocene of Othonì and Kerkira islands (Ionian Island, Greece)

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Keywords: Sea level change, wave cut platforms, tidal notch, uplift.

Geomorphological surveys of the coastal areas of Othoni and Kerkira islands have been performed in both emerged and submerged environments. High cliffs and high energetic slopes, marked by bays that guest small beaches, are shaped mainly in the Mesozoic Limestone and in the Tertiary flysh sequences.

Rocky coasts are crowned by seasonal pebble and sandy beaches. Beach rocks have been surveyed only along the southernmost part of Kerkira, faced to the Otranto Channel (Mastronuzii et al., 2014); otherwise, tidal notches have been recognised all along the coast of both islands. Wave cut platforms have been recognised below sea level in Othoni and Kerkira. If the value of beach rock in the recostruction of the sea level history is still matter of debate, tidal notches are considered as the best sea level indicator (Antonioli et al., 2015).

In both islands their presence is like ubiquitously always where carbonatic units outcrop. Actually their size is significantly bigger respect to the tidal range and their profile is complicated by the presence of a well marked step suggesting a complex origin may be conditioned by a rapid relative sea level change. Wave cut platforms, richly colonised by *Dendropoma petraeus* colonies, are in shaping at their foot.

Along the SE coast of Othoni the wave cut platform is in developping on the flysh outcrop as in some localities of the southernmost coasts of Kerkira. Just at the south limit of this last island, a large surface marked by discontinuous cover of slightly cemented sand rich in bivalves and gastropod or by vermetids concrections marks the local landscape.

Some 14C age determination suggest its origin as a wave cut platform rapidly uplifted above the sea level during the Late Holocene.

The present paper has been produced in the framework of the PRIN 2010-2011 and it is a Greek-Italian contribution to the project IGCP 639 by UNESCO e IUGS.

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Subsidence trends detected by SAR interferometry and buried stratigraphic architecture in a coastal plain (northern Campania, southern Italy)

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Keywords: Subsidence, SAR interferometry, stratigraphic architecture, Volturno alluvial plain.

Aim of the present study is the assessment of the ground deformation trends referred to almost two decades (years 1992-2008), which characterize the alluvial plain of the Volturno river, located in northern Campania coastal area (Italy). The research work is based on a temporal analysis and mapping of Persistent Scatterers (PS) data, obtained from interferometric processing of radar satellite ERS-1/2 and RADARSAT scenes of the study area.

The analyses are based on SAR data archive for the period 1992-2001 (ERS dataset) and the period 2003-2008 (Radarsat dataset). The distribution of ground deformations was compared with the stratigraphic architecture reconstructed for the whole Volturno river lower alluvial plain. Geological, stratigraphical and SAR data have been managed and analyzed in a GIS environment.

Main results are:

1) The widespread volcanic activity that occurred along the Campania continental margin during the Late Pleistocene produced significant volcaniclastic aggradation, and was largely concomitant with the eustatic regression associated with the last glacioeustatic cycle between 125 ka and 18 ka. As a consequence, a seaward shift of the shoreline and the forced regression of paralic-shallow marine depositional systems concurrently occurred, while the whole plain emerged and the paleo-Volturno river likely started fluvial downcutting with formation of a major incised valley. The resulting palaeovalley is about 15-20 km wide and up to 30 m deep in the depocentre and was originated as a response to the Last Glacial Maximum sea-level drop. The unit that forms the first substrate for the Holocene and recent sedimentation is represented by the Campania Grey Tuff (CGT), originated by the Campi Flegrei caldera 39 ka eruptions. The stratigraphic study carried out on the whole plain has permitted to reconstruct the upper surface of the GCT in the whole Plain and recognize the palaeovalley morphology.

2) the Volturno plain SAR data are characterised by high negative values of ground deformation (up to – 35 mm/year) in both ascending and descending orbit datasets and identify areas affected by significant subsidence processes with rates from −20 to −5 mm/year that mainly concentrates along the river channels, the lateral flood plains and the estuary area.

3) The spatial analysis of the SAR data and stratigraphic architecture highlighted the major ground deformation occurring within the outer boundary of the incised paleo-valley, corresponding to the Holocene alluvial/transitional filling.

Coastal Vulnerability Assessment. Study Case: Bonassola - La Spezia Italy

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Keywords: Coastal vulnerability, modelling, wave runup, gravel-sand beach, camera system.

The present work illustrates a new approach for coastal vulnerability assessment developed on a micro-tidal alluvial plain taking into account the coastal geology features and the hydrodynamic conditions. The study area (Bonassola) is located in the NW Mediterranean in the Easter coast of Liguria (NW Italy). The local scale assessment implies working at a much more detailed scale used by local beach managers. Consequently, this analysis requires full details of a beach and of a back-beach; where the essential objective is to identify zones within the beach in order to help in the decision making over the necessity of implementation of measures over protection-adaptation and/or mitigation.

This approach relies upon two sources: observed and modelling data. The first has been collected by three cameras located on Bonassola bay. These instruments recorded storm surge impact along the beach in November 2015 and the images were elaborated using the dedicated software BeachKeeper_Plus. The software is an image management and elaboration software which provides Time-Exposure, Variance, Day-Timex and Time-Stack of images (Brignone et al., 2012). Water levels at the shoreline were modeled using XBeach (v.1.22.4867 Kingsday release), which solve coupled two-dimensional (2-D), depth-averanged equations for short-wave envelope propagation and flow for varying spectral wave and flow boundary conditions (Roelvink et al., 2009).

The results show a correct simulation of the storm surge recorded, according to conditions of waves and hydrodynamic evolutions. Meteocean Hidecast was employed for the wave climate assessment along the Bonassola boundary offshore since 1999. MeteOcean group at DICCA has developed an hindcast analysis for the period 1979-2014 for the whole Mediterranean basin with a resolution of 0.1° (Mentaschi et al., 2015). Using validate setup, XBeach was used to propagate the biggest storm surges on beach, evaluating the Wave Run-Up in the last 16 years.

Following the recent guidelines supplied by Regione Liguria, a vulnerability legend for Bonassola case has been developed, taking into account the geology features and the Wave Run-up from XBeach computation. Results show that the storm surges flood the populated area in the last 16 years. The vulnerability map shown in present work could be applied on other cases and It is an efficient tool in coastal risk management.

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Historic coastal variations of the Neapolitan Area based on geoarchaeological data

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Keywords: Geoarchaeological data, coastal variations, Neapolitan Area.

Geoarchaeological studies in collaboration with the Archaeological Superintendence of Campania made it possible to make a paleoenvironmental reconstruction of the coastal area between the Gulf of Pozzuoli and that of Naples characterized by volcanic rocks, alluvial and carbonate sediments. The volcanic phenomena and the bradyseismic vertical moviments and alluvial events have significantly changed the populated coastal area. Less known are the changes that have affected the carbonate coast of the Sorrento Peninsula and Capri. Underwater surveys made it possible to identify and date the various artifacts and reconstruct the modifications relative sea level over the past millennia. In particular, it is known as, from AD 79, the Vesuvius area has been affected by repeated eruptions, which have resulted in permanent changes to the coastline, causing a continuous aggradation/progradation of the emerged coastal area. The bradyseism, negative/positive, caused, in turn, respectively, lowering/lifting of the urbanized coastal area. Since V A.D. so, on the evidence of various artifacts submerged, the entire coastal area, from the Sorrento Peninsula to Stabiae, the Coast of Vesuvius, Naples and the Phlaegrean area, has undergone a general lowering of varying amounts from about 1 m to over 10 mt. Even the urban area of Naples and the coast north of Campi Flegrei were affected by repeated catastrophic flooding, which caused overlapping/obliteration of urbanized areas and progressive coastal aggradation and progradation. In addition, the paleoclimatic reconstructions showed that, in historical times, cyclically alternated periods of warmer and dry weather, other more cold and wet. The morphology of the Naples area was conspicuously conditioned and shaped by the action of the volcanic district of Phaegrean Area and Somma-Vesuvius. In conclusion, the geoarchaeological characterization of the areas belonging to the two gulfs of Pozzuoli and Naples made it possible to reconstruct the vertical movements of the volcanic and carbonate bedrock which show a significant relative change in sea level affecting the carbonate bedrock considered relatively stable compared to the Phlaegrean area. This phenomenon is due, probably, to vertical crustal movements.

Geomorphology and vertical rate of subsidence in the last ≈2ky in the coastal sectors of the Pozzuoli Bay, Phlegrean Fields Caldera, Naples (Italy)

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Keywords: resurgent caldera, vertical rate of movements, hydrothermal system, multibeam swath bathymetry.

The coastal and shallow marine sectors of the Pozzuoli Bay represent the seaward prosecution of the highly active Phlegrean Fields volcanic district, SW Italy. The area is structurally dominated by a caldera collapse, ~8 km in diameter, associated with the eruption of the Neapolitan Yellow Tuff (NYT), a 30-50 km^3 Dense Rock Equivalent (DRE) ignimbrite dated ~15 ka B.P. Here we show the main results of several oceanographic cruises developed in the last 10 years in the whole Pozzuoli Bay. A 1:10.000 scale morpho-bathymetric map was produced, derived by 1 m cell-size, colour hill-shaded, Digital Terrain Model (DTM) of the seafloor (Somma et al., 2016). Morphometric analysis allowed the development of a number of thematic maps, including slope, profile curvature and aspect. A complete dataset of active fluid vents seafloor locations were also recorded during the survey.

Multibeam bathymetry data reveal the precise location near the current coastline and the extent of the Roman underwater archaeological remains, that also include the military complex of Portus Iulius and the ancient thermal and villa complex of Baianus Lacus, located in the infralittoral zone of the Bay. Additional multibeam data at 0.1 m grid cell-size (Passaro et al., 2013) allowed an unprecedented detailed imaging of the seafloor morphology. Roman epoch remains, in particular, allowed to roughly define the average rate of subsidence due to bradyseism in the last 2 ky, resulted to be 2.55 (+/- 0.5) mm/y for the Eastern sector (Pozzuoli) and 2.90 (+/- 0.5) mm/y for the western (Baia). This approach allow to gain a further step to the understanding of the dynamic evolution of the Phlegrean Fields caldera, a high-risk volcanic area densely populated by almost 1 million people.

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Coastal area planning based on *dune vulnerability index* and *carrying capacity* in northern Campania (Italy)

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Keywords: Coastal morphology, coastal sedimentology, dune vulnerability index, beach carrying capacity.

The beach and dune zone included in the coastal area located to the left of the Garigliano River mouth have been studied. Physical and biotic factors were evaluated by multidisciplinary approach, and the results obtained allowed to identify the critical area where appropriate actions can be performed for the mitigation of impacts, the conservation of dune habitats and its sustainable use. We evaluated the level of dunes vulnerability (Dune Vulnerability Index - DVI) and sustainable anthropogenic load (carrying capacity) of the emerged beach. The first summarizes quantitatively the responsiveness of the coastal dune system to the different processes and effects of human pressure. The second analyzes the relationships between sedimentological and morphological features, density and distribution of users, quality and service distribution, safety bathing, in order to identify the level of anthropogenic load that a given environmental can bear. The studies highlighted the severity of the erosion of the beach and dune system. The effects of these processes are also reflected on the vegetation, that highlights critical conditions such as to endanger the subsistence of several local species. The erosion processes are related to the pressure of human activities, that have operated over time in both direct and indirect manner, activating and/or accelerating a reduction in the resilience of the natural system

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Coastal dune development and morphological changes along the Garigliano Plain, Italy, and Elis, Greece, during the Holocene

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Keywords: coastal geomorphology, sedimentology, coastal dunes, geoarchaelogy, sea level change, Holocene.

The Garigliano Plain and the Elis littorals show similar geoenvironmental features: both are in Mediterranean climate regions, modeled by western winds and storms, characterized by wide sandy coastal dunes parallel to the present shoreline, with pumices, and locally anthropized.

The Garigliano coastal-marine facies are characterized by Holocene dune and aeolian deposits (Abate et al., 1998) related to Tyrrhenian highstand (125 kyr BP). A dual dune system with a depression, in which the wetland of Pantano di Sessa was formed, is present. The beach is bounded landwards by a dune system emplaced during the Holocene transgression (6 kyr BP). This dune system originally included more ridges than six remnants, whose age increase inland. Geoarchaeological surveys highlighted the presence of a Roman road that cut the dune, whose age is older than Graeco-Roman Period. Since the end of the 50s, strong littoral retreat affected the beach-dune system, mainly due to human activity. Currently the front dune consists of embryo dunes, leaning against a secondary dune, generally well-vegetated (Pennetta et al., 2011, 2016).

The coastland of Elis is characterized by Quaternary marine deposits. Three significant morphogenetic phases occurred during the Holocene (Kontopoulos & Koutsios , 2010). The first, from 7000 to 3810 BP, was characterized by deposition of beach sediments and development of dunes. During the second phase, from 3810 to 1400 BP, the rate of sedimentation was high, mainly with accumulation of fluvial deposits coming from Peneus River mouth. During the last phase, from 1400 BP to current, shoreline retreat and deposition of aeolian sands occurred. Geoarchaeological evidences suggest that this phase is related to a sea-level lowstand followed by a slow sea-level rise up to the current position, and by humid-temperate climate.

Geomorphological surveys of the Holocene dunes of Garigliano Plain and Elis, each other compared, suggest that the main phases of their development are related to the effects of sea-level changes, climatic conditions, and secondly to human activity.

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Boulder dynamics in the Favignana Island coastal zone (Egadi Archipelago, Central Mediterranean)

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Keywords: Boulder, storm wave, socket, hydrodynamic equations, Favignana Island, Egadi Archipelago, coastal zone.

Boulders disjoined from platform edges or accumulated in the nearshore are frequently transported and deposited in the backshore as a consequence of tsunamis and high-magnitude storm waves. We investigate this process in the Favignana Island (Egadi Archipelago) coastal zone by integrating geological and morphological data with numerical hydrodynamic analysis and radiocarbon dating.

Boulders and sockets are detected in proximity to the shorelines of Punta Faraglione and Punta Fanfalo, which are located in the NW and SE sectors of the Favignana Island, respectively. They are scattered on the rocky platform as isolated blocks or in small groups that, together, form a discontinuous berm. The latter is characterized by an imbricate structure in which the A-axis of boulders steeply dips toward the sea. The boulders are composed of grainstones and marl deposits of Early-Middle Pleistocene age. Most of them are covered by marine biogenic incrustations. The boulders exhibit a tabular shape with sharp broken edges. Their shape, length and width appear to be influenced by litho-structural features of the rocky platform. In fact, the thickness of bedding planes and fracture network are particularly of interest because weathering and wave action (i.e. hydraulic action, abrasion, attrition and solution) operate simultaneously in these discontinuities to weaken them. The histogram of boulders' thicknesses shows three main peaks that correlate with the thickness of the strata of coeval deposits cropping out close to the town of Favignana.

Numerical hydrodynamic analysis is used in order to determinate both the minimum flow velocity and the tsunami and storm wave height that satisfy the requirements to initiate the transport of a boulder. For each boulder mapped in the coastal zone, two pre-transport conditions, which are submerged and joint bounded, are considered. In particular, we applied equations that differ for submerged blocks because of their initial transport mode (sliding, rolling/overturning, saltation/lifting). Hydrodynamic modeling indicates that among all of the considered scenarios for each boulder, there is at least one case in which the wave height required to start its transport is compatible with the significant wave heights recorded by the RON buoy of Mazara del Vallo.

The historical data of tsunami and storms events, the results of the hydrodynamic equations, the radiocarbon dating, the dispersion of the A-axis direction, and the presence of small boulders with striae due to a fresh impact coherently suggest that boulder deposits in the Favignana Island coastal zone are polyphasic.

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Coastal erosion and protection in Europe

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Keywords: coastal erosion, human impact, shore protection, beach nourishment.

The presentation, running along the Atlantic coast from Portugal to Russia, to enter the Mediterranean and the Black Sea, deals with the erosion processes affecting European coast and the solutions developed to oppose it.

Coastal erosion was a minor issue in historical times in Europe, but since the mid 19th century it became a dominant process. Deforestation, river damming and river bed quarrying, together with the construction of harbours on sand coasts are the main causes of this process in most of the countries.

Vernacular solutions were firstly adopted to contrast the sea eroding the beaches, but later experience sharing and numerical and physical models availability allowed to design more complex structures. Consequently, a variety of solutions are now present along the European coasts, some adopted in most of the countries, like groins and seawalls, other specific of some areas, like permeable or submerged groins. Recently, innovative and experimental projects have been adopted, whose results are still under discussion.

Beach nourishment was limited in the past, using mostly sediment quarried in the rivers or in alluvial plains; but the possibility to dredge huge amount of aggregates on the continental shelf made this technique the most suitable for large projects, possibly flanked by restrain structures. Hard protection projects are now unpopular and old archostructures somewhere removed or razed to mean sea level.

Cultural, administrative and political conditions are part of this issue, influencing strategies and technical solutions. Examples are found in ex Soviet Union countries, whose coasts were defended with very hard protections, which are now completely destroyed and impossible to be restored due to economical conditions of those countries. On the opposite side The Netherland, where hard protections are almost banned and dune reconstruction carried out with offshore sediments. Here relative sea level rise is the major concern.

The history of the coastal area urbanization is considered as well: towns, industrial plants, roads and railways built close to the shoreline had to be protected with seawalls, frequently inducing the beach disappearance.

More recently, holidays villages expanded over dunes; when beach erosion threatened them, seawalls could not be used since sand had to be maintained for recreational use. Groins and detached breakwaters were preferred, each protecting a small coastal segment but triggering downdrift erosion.

Aware that this strategy could not be sustainable for a long time, beach nourishment became the favourite solution in many countries, with approximately 28 million cubic meters of sand used in Europe each year. Easy for those countries overlooking the sand-rich North Sea, but very problematic in the Mediterranean Sea, where this resource is limited and the risk of environmental disaster larger.

Future scenarios related to global worming and sea level rise will make coastal protection issues even more topical and the knowledge of what happened in the past is the best instrument to read the future.

Coastal susceptibility assessment and vulnerability evaluation in Valdelagrana spit (SW Spain)

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Keywords: Coastal susceptibility, coastal vulnerability, SW Spain.

Valdelagrana spit is located at the Bay of Cadiz, a semidiurnal, mesotidal environment in SW Spain. The spit, with an average width of 1.5 km and 7 km in length, encloses the San Pedro tidal creek and is limited in the Northern part by two jetties (at the Guadalete River mouth) and by an artificial fill in the Southern part. It includes several morpho-sedimentary environments: a sandy beach, embryo dunes and discontinuous ridges of foredunes, mud flats and wide areas of vegetated salt marshes. The spit shows different levels of human occupation: the northernmost sector is densely urbanized while the rest of the area is part of a natural protected area belonging to the Bahía de Cádiz Natural Park. During the second half of the 20th century, intense geomorphological and morphodynamic changes have been caused especially by human activities and reflected extreme shoreline retreat at the southern sector. The aim of this study is to present the results of coastal susceptibility to erosion and inundation processes by means of indexes-based method. The proposed indexes take into account both physical and marine parameters, such as dune and beach geomorphological characteristics, shoreline evolution, local significant wave height and relative run-up. A model has been compiled into a GIS environment to elaborate spatial input data. The results highlight that the area has an high physical susceptibility especially in the southern end of the spit where the erosion rates are higher and the dune system is low and discontinuous. The vulnerability of the area has been evaluated by considering the main land use categories and the presence of important natural and ecological areas. The overlay of the physical parameters with the exposed assets pointed out that the presence of an important touristic settlement (rapidly developed in the last decades) and a wide natural area have increased the vulnerability of Valdelagrana spit, which requires local management and defense strategies.

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Recent evolution of the Molise coast of Italy: present dynamics and critical issues

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Keywords: beach erosion, meteo-marine influence, coastal vulnerability, Adriatic coast.

The Molise coast in Italy has a length of just 36 km and is part of the central Adriatic coast. It falls within the physiographic unit P.ta Penna (Abruzzo) - P.^{ta} Pietra Nere (Apulia), but consists of two nearly independent coastal sectors separated by the Termoli promontory (Aucelli et al., 2009) and with WNW-ESE and NW-SE orientations, respectively. This region has a microtidal regime with ordinary tidal excursions of 30-40 cm and an overall N-S directed longshore drift.

The Molise coastline is characterized by low and rocky shorelines. The low coast sections extend for 22 km and are comprised of alluvial coastal plains of fine, clayey-silty deposits and sandy to locally gravelly beaches (Aucelli et al., 2009). The rocky coast section is cut into Plio-Pleistocene clayey-sandy-conglomeratic successions.

The Molise coast began to experience shoreline retreat at least from the mid-1950s onwards (Aucelli et al., 2009) that caused an overall land loss of approximately 1,000,000 m^2 during the last 60 years and partial to entire erosion of most of its coastal dunes. GIS analysis on shoreline variations from 1954 to 2014, considering the coast subdivided into several stretches, shows that erosion rates are not uniform in space or time. Over the entire study period, the two coastal stretches including the major river mouths (Trigno and Biferno), extending for a total length of 10 km, experienced average erosion rates of - 2.7 and - 3.28 m a^{-1}, respectively, while the other reaches remained stable or prograded slightly (max. 1 m a^{-1}). To limit shoreline erosion, many hard coastal-defence structures were built over time, now covering approximately 65% of the coast, but with limited success. Erosion rates have increased from the 1990s onwards and reached maximum values in the periods 1998-2004 and 2011-2014, affecting also other reaches beyond those including the Trigno and Biferno river mouths.

Presently, erosion is a prevalent concern along the Molise coast and fragmentation of the beach-dune system is increasing the vulnerability of the region. The key driving factors contributing to this erosion and recent geomorphological evolution of the coast include: i) coastal protection structures that alter littoral processes and sediment budgets, ii) hydro-geomorphic function and change in major watercourses flowing to the Molise coast (Scorpio et al., 2015), and iii) tele-connected atmospheric-oceanic forcing and related climatic variability effects.

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Insights into the Holocene evolution of the Volturno river delta system, Eastern Tyrrhenian Margin

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Keywords: Volturno river delta, Holocene stratigraphic evolution, reclamation interventions, coastal erosion.

The present study focused on the Holocene stratigraphic evolution and the Recent morphologic and hydraulic changes occurred along the coastal Campania Plain, in southern Italy along the eastern Tyrrhenian Sea.

The Campania Plain has developed following the Holocene glacio-eustatic sea level rise after the Last Glacial Maximum. The establishment of the coastal progradational phase, in the last about 6000 ky BP, allowed the formation of a wave-dominated delta system of the Volturno River, with flanking strandplains forming beach-dune ridges partially enclosing lagoonal-marshy areas. The progradation of the Volturno delta allowed the development of continental environments, characterised by marshes and wetland as an integral part of the alluvial flood plain within the delta system. The formation of a mature sand bar complex offshore caused a progressive isolation of the former coastal lagoonal area from the open Tyrrhenian Sea. About 2 ky cal BP, beach and lagoonal environments still persisted along the present coastal zone.

Most of the marshy areas were reclaimed from 1811 until the early 1900s. As a result of the reclamation interventions, the development of agricultural and farming took place as well as a strong urbanization. The Volturno River delta plain and related strandplain underwent major morphological changes.

The reconstruction of Holocene stratigraphy relied on a dataset including about 300 lithostratigraphic logs. The analysis of the historical cartography and the comparison with recent maps in a GIS environment provided a sufficiently exhaustive picture of the Recent evolutionary trend of the studied littoral.

From the Roman times to the last century, the entire coastline has experienced progradational trends. The GIS analyses allowed to record the peak of progradation of the Volturno delta system during the 1800's after which it began to evolve from cuspate to arcuate in a strongly asymmetric form. In fact, the first anthropic interventions along coastline and the catchment area reduced the volume of sediment available for the sedimentary balance, so that in the last century the erosion at the delta mouth was registered. The eroded sediments of the cuspate delta apex were gradually stored by longshore transport along the lee-side; at the end, the shoreline has become parallel.

The comparison between bathymetric measurements conducted in the 1887 and in 1987 enabled a detailed assessment of the morphological changes occurred during the last century showing the sea bed most severely eroded near the wings of the delta; by contrast, in the northern and southern parts more sediments were deposited offshore.

The latest Quaternary evolution of the Volturno delta system has been also imaged by ca. 60 km of high-resolution (sparker 1KJ) single channel reflection seismic profiles acquired off the river mouth in the Gaeta Gulf, that document the onset of the prograding prodelta sequences since the mid Holocene (ca. 6,5 ka BP).

Late Pleistocene sea-level changes and vertical movements between Formia and Minturno, central Italy

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Keywords: Coastal Geomorphology, Quaternary tectonics, 230Th/234U dating, central Italy.

The Tyrrhenian coast of southern Lazio, central Italy, is one of the most representative coastal segment of the Italian peninsula from a morphotectonic viewpoint. Many markers of Late Quaternary sea-level changes have been surveyed In this area (Ozer et al., 1987; Antonioli, 1991; De Pippo et al., 2007). The whole south-facing arched coastal plain is relatively narrow being immediately bordered at its back by an impressive mountain ridge (Aurunci Mts) made of Mesozoic-Cenozoic carbonate rocks and terrigenous units. The coastal belt ranges from the sea level to about 30 m a.s.l. and is geologically constituted of several Quaternary units, partly cropping out in the inner portion of the study area, and by a Holocene sequence known only by well logs. A new geological survey associated to detailed measures of sea-level markers has been carried out along the Gaeta Bay coastline, from Vindicio plain to Monte di Scauri promontory (respectively to the west and the east of Formia town) and at Monte d'Argento in the Minturno plain. In the Vindicio area, a carbonate clastic deposit, never reported before in the maps of this sector, has been found at about 17 m a.s.l.: petrographic analysis of thin sections of these sediments suggested a deposition in an intertidal littoral environment as beachrock deposits. Different cementation facies indicated an early cementation in a littoral environment followed by supratidal main cementation. ^{230}Th/^{234}U isotopic analysis revealed a Late Pleistocene (pre-Tyrrhenian) age. It can be assumed that the area of Vindicio underwent a remarkable tectonic uplift in Quaternary times. At Monte di Scauri and Monte d'Argento sites fossil notches, lithodome holes, beach deposits, and other geomorphological markers are well exposed and locally displaced by faults. Data there collected allowed us to complete the framework of the morphotectonic evolution following the uplift occurred in the Late Pleistocene and indicated that the area was subject to a significant tectonic activity also during the Tyrrhenian up to the MIS 5.1.

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Landslides and sea level changes: evidence of the complex geomorphological evolution of the NW coast of Malta from exposure dating using cosmogenic nuclides

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Keywords: Landslides, Climate changes, Cosmogenic nuclides dating, Malta.

Along the NW coast of Malta, extensive block slides affect limestone plateaus and the underlying clayey terrains. These mass movements have been mapped (Devoto et al., 2012), largely investigated and monitored since 2005 (Mantovani et al., 2013). The different geomechanical properties of the lithologies involved are responsible of tensile stresses witnessed by a dense network of fractures that isolate large pillars and blocks from the limestone plateaus. Persistent Scatterer Interferometry analysis and long-term monitoring highlighted that most of the coastal block slides are active. A bathymetric survey was carried out in 2012 offshore the NW coast of Malta and identified large block accumulations extending from the coastline for 700 m and up to a depth of ca. 40 m (Foglini et al., 2016). These have been interpreted as the prolongation of the coastal block slides above mentioned, thus constituting single landslide deposits whose emerged portion is about one-third of the entire accumulation.

Recently we have focussed on attempting to understand if block slides onset and activity were somehow related to the post-glacial marine transgression. The work has been made on the following hypotheses: i) block slide onset occurred under the influence of post-LGM sea-level rise which would have contributed to landslide triggering; rising sea level would have then covered and sealed part of the landslide accumulation; ii) block slide onset occurred before or during the LGM in a subaerial environment; hence, sea level rise would not influenced landslide onset. Though geomorphological evidence was supporting the second option, in order to correctly define the palaeo-environmental conditions in which the block slides were activated and developed, exposure dating using cosmogenic nuclides was performed. Samples from landslide scarps and displaced blocks of relevant sites (Anchor Bay and Il-Qarraba) were collected for ^{36}Cl dating. The most ancient landslide detachment was dated back to ~32 ka at Anchor Bay, while at Il-Qarraba the most ancient block detachment was dated back to ~19 ka. Considering sea levels at those times and the fact that landslide tips are at present located not lower than -40 m b.s.l, it can be stated that block slides were already active during the LGM, and occurring in a subaerial environment when the sea level was much lower than the maximum depth at which landslide deposits can now be found. Further dating showed that older detachment events are located more inland. This suggests that block slides may have been developed as a result of first-time failures involving large portions of the slopes and of successive secondary displacements. The latter at some stages are likely to have occurred due to sea action during rising sea level.

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Permanent and ephemeral modifications of the Amalfi Coast after the AD 79 eruption of Vesuvius: environmental effects and geohazard implications

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Keywords: Amalfi Coast, Rocky coast, Coastal changes, fan-delta, AD 79 eruption, flash flood.

The Amalfi Coast consist of a steep mountain front that rises abruptly from the Tyrrhenian Sea in southern Italy. It is mostly formed by Mesozoic carbonate rocks deeply cut by a complex of bedrock rivers and channels with main delivery areas into the adjacent continental shelf. The coastal streams drain high-relief basins and have high-gradient steep-sided profiles discontinuously covered by reworked fall-out deposits of the AD 79 Somma-Vesuvius eruption. These deposits occur both as well lithified alluvial accumulations (locally called "Durece") along the stream valleys or as loose pyroclastic covers prone to detachment during rainfall events.

In the marine areas, a series of coalescing coarse fan-deltas occur at the mouth of the main streams resulting in an almost continuous depositional platform close to the shoreline (Violante, 2009). The fan-delta system postdates the AD 79 Plinian eruption of Vesuvius and correlate with periods of high sediment supply from the adjacent fluvial basins. A main depositional event occurred soon after the AD 79 eruption when the pyroclastic fall deposits arriving on the coastal basins entered a period of fast remobilization that was mostly accomplished by sediment gravity flows and hyperpycnal (e.g. inertia, turbidity) flows. As a consequence, an overall seaward shift of the coastline of ca 500 m was produced (Violante et al., 2009).

In recent times, alluvial fan flooding and consequent shoreline progradation frequently occurred in this area as documented by historical sources. These phenomena are caused by high-intensity and very localized cloudbursts of short duration that produce fast-moving large debris torrents (flash floods) with significant catastrophic implications for communities living at the stream mouths (Violante et al., 2016). The observed shoreline progradations are largely ephemerals, as fluvial discharges are of short duration followed by long periods of non-deposition, so that waves are free to erode alluvial deposits and restore the original conditions to a varying extent. However, the deposition of a fan-delta system along the Amalfi Coast since AD 79 has created gentle sloping alluvial fan surface at the mouth of the main streams, originally characterized by deep inlets and presently exploited for human activity and urban development.

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SESSION S14

Climate and environments from past and present interglacials: natural variability and human-induced landscape changes

CONVENERS AND CHAIRPERSONS

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The interglacials 5 and 7 in the sedimentary record of the Ross Sea continental slope (Antarctica)

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Keywords: Paleoceanography, Quaternary, Ross Sea continental slope.

The Antarctic area produces bottom waters that ventilate much of the deepest part of the ocean. The strength of this source of cold bottom waters and the flow of these towards the equator, are key factors in the general thermohaline circulation, both for the present and past climate. In this view, as part of a PNRA project, we studied MIS 5 and MIS 7 with a highly multidisciplinary approach. The studied sequence was obtained from a sediment core collected in the Ross Sea continental slope offshore the Drygalski Basin to a water depth of 2377m, where the HSSW produced in the Terra Nova Bay polynya cascades into the Southern Ocean.

The core chronology is based on the climatic curves and bioevents by diatom assemblages. The pelagic signal was provided by the diatom assemblages (seasonal variability of sea ice cover) together with the changes of biogenic silica and $\delta^{15}N$ on the organic fraction of the sediment (degree of nutrient utilization), dinoflagellates, quantity of Ice rafted Debris (IRD) and changes of TEX_{86}, which is an organic geochemical proxy of surface paleo-temperature. The benthic signal was obtained from the assemblages of agglutinated foraminifera, $\delta^{13}C$ of organic matter, minero-chemical data (biological productivity, bottom water ventilation, source of the detrital component) and excess ^{230}Th (sediment focusing). Within the two MISs, were distinguished intervals with greater abundance of diatom tests, which were interpreted as substages 1-5, consistent with other proxies (biogenic silica, Ba_{exc}, OC, IRD).

The two interglacials show high biological productivity (abundant biogenic silica, high occurrence of diatoms), consistent with the negative shift of $\delta^{15}N$ (greater nutrient availability). This high productivity seems to be mirrored from the seabed by the higher OC accumulation, the presence of benthic foraminifera typical of high productivity environments and conditions of relatively lower oxygenation (V/Cr). The paleotemperatures at the indicate a greater heating of about 2°C in the interglacial 5.5 compared to 7.5. These interglacials also show a rapid retreat of the sea ice (IRD> 2mm). However, the retreat of the sea ice seems to take place in different ways for the two MISs: IRD absence in the MIS 5, except at its base, and reappearance of IRD in MIS 7.4 and 7.2. The MIS 7 seems to include two steps in the iceberg release. This inference does not conflict with the ice core record of Dome C.

The record obtained is currently one of the paleoenvironmental reconstructions with the highest time resolution existing in the literature of Antarctica, also taking into account the additional difficulty due to the near absence of carbonates in the area.

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The Bisenzio Project: preliminary results of the first year research

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Keywords: Bisenzio, Central Italy, geoarchaeology, landscape evolution.

This work introduces the preliminary results of a three years lasting multidisciplinary research project which started in 2015.

The research program focuses on the Etruscan settlement of Bisenzio, that flourished between 10th and early 5th century B.C on the south-western shore of Bolsena Lake (Central Italy).

Actually, Bisenzio played a pivotal role as a node in the networks connecting the centers scattered along the Tyrrhenian coastline and those located in the Tiberina area (between the eastern shore of the Bolsena Lake and the Tiber Valley). Despite its importance, the urban and funerary evidence form Bisenzio was only scarcely studied and rarely published.

The project, still in progress, has been carried out by an international research team, supported by the Deutsche Forschungsgemeinschaft (German Research Foundation) and enabled by the permits the Soprintendenza Archeologia del Lazio e dell'Etruria Meridionale conferred to Dr. Babbi.

The main goal is to elaborate a thorough study of Bisenzio intended as a complex system formed by settlement, suburb, cemeteries, and deeply connected to the neighbouring landscape.

Alongside the study of evidence from the settlement and from one of its richest burial grounds (i.e. Olmo Bello necropolis), the research aims at the reconstruction of the landscape during the Bronze and the Archaic Ages, and at the acknowledgement of ancient traces of territory organization.

First outcomes are presented about geomorphological and geo-pedological surveys and the recognition of landforms and deposits related to the action of morpho-evolution processes.

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Human-Environment Relationship and Landscape Evolution since Etruscan Times: Case Studies from Apuo-Versilia Plain and Pisa Urban Area (NW Italy)

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Keywords: Geoarchaeology, Geomorphology; Anthropocene, Pisa, Apuo-Versilian plain.

During the last millennia human and natural processes in the Mediterranean Basin have become strongly intertwined, modifying the Earth's surface in many different ways (Butzer, 2008; Zanchetta et al., 2013). Evident traces of this joint human-nature activity can be detected in coastal areas and alluvial plains, where an enduring synergic relationship commonly occurs between landscape, ancient cultures and society evolution (Butzer, 2008).

A holistic geoarchaeological approach helps understand the history of these areas encompassing both natural and human-induced changes. In this regards interesting cases are the Apuo-Versilia plain and the Pisa urban area.

For instance the Apuo-Versilia plain experienced a discontinuous progradation of the coastline between Etruscan times and the Middle Ages. A change in the progradation rate was documented after Modern Age and was related to an increase in flood frequencies due to the overlap of climate events and human impact (Bini et al. 2013).

Whereas, Pisa is a multilayered city located nowadays on a 4 m-high mound composed of anthropogenic, made-ground deposits dated from the Roman period onwards (Bini et al., 2015). These deposits, totally due to human activities, overlie alluvial, man-modified sediments recording intense human frequentation in a context of a natural environment developed since the early Etruscan age. Changes in Pisa topography through time, quantified using stratigraphic data and the Digital Elevation Model for five historical periods, indicate that the maximum increase in volume and thickness of anthropogenic deposits occurs during the Etruscan-Roman transition, which potentially corresponds to the local onset of the Anthropocene. Integration of DEM analysis with high-resolution stratigraphy allows to reconstruct the spatio-temporal distribution patterns of human frequentation and urban ground growth.

The comparison of these two sectors, therefore, indicates interesting relation between human activity and change in the landscape.

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Climate and humans at Soknopaiou Nesos (Northern Faiyum, Egypt) during the Holocene

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Keywords: Faiyum Lake, Soknopaiou Nesos, Egypt, lake level changes, human exploitation.

The geoarchaeological research carried out from 2008 to 2011 in the frame of the Archaeological Mission of the Salento University (directed by M. Capasso and P. Davoli) in the northern reach of the Faiyum Lake in the area of the Ptolemaic temple of Soknopaiou Nesos had the main purpose to reconstruct the climatic and paleoenvironmental changes occurred in the area and their relationship with the human exploitation of the area. Human communities settled the shores of the Faiyum Lake from the Epipalaeolithic period to the Islamic Era. In the area, lacustrine deposits related to the high stand of the Faiyum Lake (Mega-Qarun Lake phase) are well developed. They consist of calcareous mud and peat corresponding respectively to open lake and shore facies. Sediments were radiocarbon dated from 9500 to 5500 years BP; sedimentological and isotopic (C and O) analyses indicate minor fluctuations of the lake level during this period and an increase of organic sedimentation toward the top of the sequence, thus suggesting a drop of the lake level. Along the shore of the lake, several archaeological sites from Epipalaeolithic to Early Dynastic periods suggest different exploitation strategies of freshwater resources. An abrupt drop of the lake level is indicated by progradation of sand dunes on the previous lacustrine deposits. However, minor playa basins still persisted in the area probably during the Dynastic and Ptolemaic periods, which provide water supply for cultivable land around the Soknopaiou Nesos temple and the surrounding village. Finally, the evidence of a further rising of the lake level recorded by shorelines and related sediments is dated on the base of radiocarbon ages to Medieval times.

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A long term perspective on the Hadley Cell evolution: from the last glacial maximum to climate change projections

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Keywords: Hadley cell, climate change, last glacial maximum, future climate projections.

The Hadley circulation consists of two cells, with an upward branch near the equator and downward branches in the subtropics, joined by a poleward flow at top of the troposphere and equatorward at the surface. The position of its poleward edges determines the extension of the equatorward transport of moisture and the location of Earth's arid regions. The Hadley circulation terminates poleward where the vertical shear becomes baroclinically unstable and mid-latitude baroclinic eddies occur. Here we analyze a large ensemble of climate simulations including the last glacial maximum, mid-Holocene, preindustrial, historical, rcp2.5, 4.5, 6.0 and 8.5 projections. This allows to investigate the link between Hadley cell extension and factors controlling it (global mean surface temperature, mid-latitude static stability, temperature difference between equator and subtropics, meridional potential temperature gradient in the baroclinic zone) across the widest possible range of simulated climates. We show that variations of the global mean surface temperature and mid-latitude static stability explain the substantial expansion (about 4.5 degrees) of the Hadley circulation from the last glacial maximum to the end of the 21st century. The two hemispheres are expected to respond differently to global warming and the sensistivity of latitudinal extension of Southern Hemisphere Hadley circulation is double that of the Northern Hemisphere.

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Volcaniclastic debris flows related to 472 AD eruption at Vesuvius: social and environmental impact from stratigraphic and geoarcheological data

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Keywords: Volcanology, Archaeology, Vesuvius eruptions, debris flows.

There is a growing number of evidences in the surrounding plain of Somma-Vesuvius volcano which indicate that along with primary volcanic processes (i.e. fallout, pyroclastic density currents) the syn-eruptive and post-eruptive volcaniclastic remobilization has severely impacted the ancient civilizations, which flourished in the area. This represents an important starting point for understanding the future hazard related to a potential (and not remote) renewal of volcanic activity of the Campaniana volcanoes. We present geoarcheological and stratigraphic data obtained from the analysis of more than 100 sections in the Campanian plain showing the widespread impact of volcaniclastic debris flows and floods originated from the reworking of the AD 472 eruption of Somma-Vesuvius both on the environment and on the human landscape. This eruption was one of the two sub-plinian historical events of Somma Vesuvius. This event largely impacted the northern and eastern territory surrounding the volcano with deposition of a complex sequence of pyroclastic fallout and pyroclastic current deposits. These sequences were variably affected by syn- and post-eruptive mobilization both along the Somma-Vesuvius slopes and the Apennine valleys with the emplacement of thick mud- and debris-flows which strongly modified the preexisting paleogeography of the Plain with irretrievable damages to the agricultural and urban landscape.

The preexisting landscape was characterized by intense human occupation but characterized by a strong evidences of abandonment due to the progressive decline of the Roman Empire. The impact of volcaniclastic debris flow continued for decades after the eruption as highlighted in the studied sequences by the presence of 512 AD ash layer, and contributed to the final decline of the Roman civilization in the area.

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The Pomici di Avellino Plinian eruption of Vesuvius: impact on Early and Middle Bronze Age human settlement in Campania (Southern Italy)

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Keywords: Volcanology, Archaeology, Plinian eruption Impact, Climate, Vesuvius.

The Pomici di Avellino eruption is one of the largest impact explosive events of Somma-Vesuvius (southern Italy). It occurred during the 20th–19th century B.C. when Campania was densely inhabited, following a very long period of quiescence of the volcano. The systematic revision and re-examination of the archaeological data available for the Palma Campania culture sites (Early Bronze Age) in the Campania region (southern Italy) has allowed an estimation of the territorial impact of the Vesuvius Pomici di Avellino eruption. Before the eruption the Campania region was densely inhabited, as testified by the discovery of numerous villages and cultivated areas, which indicate a well-developed level of socio-economic organization. The Pomici di Avellino eruption had a very strong impact on a large area, striking both the Campanian Plain and the surrounding Apennine Mountains. This was due to both primary volcanic deposits (i.e. fallout and pyroclastic density currents) and syn-to-post eruptive volcaniclastic debris flows development. Volcanological and archaeological studies have provided detailed information concerning the local impact and have allowed a reconstruction of the various phases of reoccupation of the territories. A critical re-examination of the reports regarding the Early and Middle Bronze Age sites evidenced a prolonged period of depopulation of the area affected by the eruption. This phenomenon interested both the areas mantled by fallout and those covered by pyroclastic density current deposits. A complete reoccupation of the area only occurred at the end of the Middle Bronze Age, about five centuries after the eruption. Climate condition inferred from different regional archives seems to suggest that Avellino eruption occurred in a period characterized by relatively wet and mild climate, occurring 150-200 yr after a considerable climatic deteriotation and it was followed 200-300 yr later by a new episode of climatic aridity. However, high resolution climatic investigation on this period are still necessary.

Insights on past interglacials from Corchia Cave (Italy) speleothems

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Keywords: interglacials, terminations, speleothems, Italy, oceanography, palaeoclimate, geochemistry.

Interglacials are important periods in the context of future Earth climate because they provide insights into the possible effects of warmer-than-present global temperatures on ice-sheet response and consequent sea-level rise. The glacial terminations that precede them are also important because the rate at which a termination occurs, the termination timing, and the magnitude of the glacial-interglacial transition may influence the evolution of the interglacial that follows. A current major challenge to developing a robust understanding of past terminations and interglacial climates is linking the various proxy archives onto a common, independently derived time scale. In this talk, we compare speleothem, marine-core, ice-core and climate-modeling data to provide new insights into the timing and progression of past interglacials and the terminations that precede them, with a particular emphasis on the TII-Last Interglacial, TIV-Marine Isotope Stage 9e and the Middle Pleistocene Transition intervals.

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Preliminary results from the analyses of calcareous sinter deposits of the Serino Roman aqueduct (Campania region, Southern Italy): environmental implications

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Keywords: Calcareous sinter, trace elements, Serino Roman aqueduct, Campania Region, Southern Italy.

This study is part of the ANR RECAP/Post-earthquake Reconstruction, Ancient experiments and innovations at Pompeii multi-disciplinary international project. We focused on the analysis of carbonate deposits preserved in the water towers of Pompeii and along the channels of the Serino Roman aqueduct. The Serino aqueduct was constructed during the Augustus period of the Roman Empire mainly with the aim of supplying the Misenum Roman fleet. It runs from Serino, where the karst spring of the Acquaro-Pelosi is located, to Pozzuoli and a branch has supplied Pompeii during an unknown period before the 79 AD destruction of the city.

The investigations are focused on an area between the Serino spring and Palma Campania. This is a particularly interesting section because variations of the route of the aqueduct and reconstructions in several places due to natural causes are testified (Sgobbo, 1938). At Ponte Tirone locality, two parallel aqueduct channels of different ages and heights can be observed, their relationship and operating conditions are still to be understood. Several remnants channels of the aqueduct are also described between Castel San Giorgio and Palma Campania. Inside many of these channels calcareous deposits, whose thickness varies from 1 to 15 cm, are preserved and were collected for analyses. Deposits from the "Castellum aquae" and two water castles from Pompeii were made available to us for comparisons.

Micromorphological, microtextural observations, trace element analyses and stable oxygen and carbon isotope analyses were carried out on a batch of selected samples.

The optical microscope and SEM observations show that these deposits are constituted by couplets of alternating sparitic laminae of elongate calcite crystals and micritic laminae. According to some authors (e.g. Sürmelihindi et al., 2013), laminae couplet can be directly linked to annual cycles and therefore can provide an annual record of operation and potentially high resolution environmental data.

The trace element analyses highlight changes in the element composition among some samples that are interpreted as due to modifications in the water supply source. Preliminary stable oxygen and carbon isotope results allow to compare the cyclicity in $\delta^{18}O$ and $\delta^{13}C$ with the lamination visible in the samples and to test the correspondence between the isotope values and the couplet of alternating laminae, in order to establish if the periodicity of isotope values may be correlated with annual layering.

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Palynological and geoarchaeological evidence of human environmental interaction in shaping the landscape at Pantanello (Metaponto, Southern Italy) in Classical times (7th-1st century BC)

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Keywords: Pollen, soil micromorphology, geoarchaeology, landscape evolution, archaeological site, Southern Italy.

This contribution describes the results of palynological and geoarchaeological analyses carried out on the archaeological site of Pantanello, in the ancient territory of Metaponto, located along the alluvial plain of the Basento River, in Basilicata (Southern Italy). The Metaponto area, investigated since the '70s by the Institute of Classical Archaeology of the University of Texas at Austin (director: J.C. Carter), is an example of the continuous interaction between human communities and the environment (Carter, 2008; Florenzano & Mercuri, 2012). A total of 28 pollen samples and 43 samples for sedimentological analyses were collected from three 2-meters-deep trenches excavated near to the archaeological site and in the alluvial plain. The palaeoenvironmental setting of the Pantanello area, as suggested by the pollen spectra, was characterised by wetland and freshwater vegetation, indicating the local presence of a high-standing surface aquifer. According to the main phases of increase/decrease of aquatics recorded in pollen spectra, we inferred several fluctuations in water level of the surface reservoir, which were likely related to both natural and anthropic forces. Besides the local habitat hints, the main elements of natural and human environments detected by pollen analyses point to a diversified mosaic of habitats. The landscape was open, covered by grasslands without densely forested areas near the site; since the 7th century BC cereals, grapevines, and some legumes were cultivated, and pastoral activities have been also carried out in the area. Accordingly, also pedosedimentary data suggest a similar scenario of progressively more open environment and increased surface processes (colluvial processes) triggered by wood clearance and intensive agricultural activities.

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Last Interglacial climate variability at TALDICE, East Antarctica

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Keywords: Antarctica, water stable isotopes, ice cores, Eemian.

The Antarctic ice sheet is a powerful archive of past climate variability and the EPICA ice core has already provided us with one of the most astonishing records of temperature and greenhouse gases over the past 800,000 years. The last interglacial period, also known as Eemian (ca. 132–116 ka BP), characterized by global temperatures and sea level higher than today, has been found in six East Antarctic ice cores: Vostok, Taylor Dome, Dome F, EPICA Dome C, EPICA Dronning Maud Land and TALDICE.

Paleotemperature reconstructions from Antarctic ice cores rely mainly on δD and $\delta^{18}O$ records while the deuterium excess, $d = \delta D - 8*\delta^{18}O$, contains information about climate conditions prevailing in the source regions of precipitation and can be used as an integrated tracer of past hydrological cycle changes.

A previous study (Masson-Delmotte et al., 2011) has shown that the $\delta^{18}O$ records obtained from these ice cores depict a quite homogeneous pattern during the present and last interglacials. The regional differences, particularly important in the case of the TALDICE ice core, may be related to both elevation changes and sea-ice variability. Talos Dome is a peripheral dome of East Antarctica, located in the Ross Sea sector where a deep ice core (1620 m) has been retrieved. The TALDICE coring site (159°11'E 72°49'S; 2315 m a.s.l.; T=-41°C) is located near the dome summit with an ice thickness of about 1795 m and with a snow accumulation rate of 80 mm w.eq./a, about three to four times higher than East Antarctic plateau sites. Backtrajectory analyses suggest that Talos Dome is mainly influenced by air masses arriving both from the Pacific (Ross Sea) and Indian Ocean sectors.

Here we present a new deuterium excess record obtained from the TALDICE ice core analysing the high resolution samples obtained from the 5 cm cuttings between 1384 and 1414 m, corresponding to the 115-130 ka BP period. This new isotopic record will be compared to other isotopic records from other ice cores taking advantage of the common ice core chronology, called AICC2012 (Veres et al., 2013), as well as to high resolution ssNa and nssCa records obtained from the TALDICE ice core in order to understand the regional differences highlighted by this site.

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Annual and seasonal rainfall trend analysis in Europe and in the Mediterranean area

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Keywords: Precipitation, Climate regime, Trend, Europe, Mediterranean basin.

Wide-ranging researches on climate change, and on its potential, large-scale, environmental and economic consequences, have been carried out during the last decades (Caloiero et al., 2015; Longobardi et al., 2016). One of the most noticeable consequences in a changing climate is the water cycle modification and, in this process, the precipitation plays a key role, which directly affecting human society, economic activities and natural systems. Studies on seasonal and annual precipitation and its trends at local and global scales showed important variations from one area to another one (IPCC, 2013).

The present study investigates the rainfall variability in Europe and in the Mediterranean area using a gridded monthly precipitation dataset produced by the Global Precipitation Climatology Centre (GPCC). In particular, the database analysed is the centennial GPCC Full Data Reanalysis of monthly global land-surface precipitation based on 75,000 stations worldwide that features record durations of 10 years or longer. This database contains the monthly totals on a regular grid with a spatial resolution of 0.5° x 0.5° latitude by longitude, with a temporal range from January 1901 until December 2009 (Meyer-Christoffer et al., 2015).

In order to determine yearly and seasonal rainfall trends, a statistical analysis was performed. The dataset was analysed for trend, and significance assessed with the Mann-Kendall non-parametric test (Mann, 1945; Kendall, 1962). The trends slopes were calculated by least square linear fitting.

A negative trend of the annual rainfall has been observed in Africa and in the Mediterranean basin. Conversely, a positive trend in the yearly precipitation has been detected in north Europe. The results confirm the evaluations of other studies, carried out on smaller spatial scales, which evidenced marked significant trend only for yearly precipitation.

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Land use change in urban environments: a case study in southern Italy

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Keywords: Land use, landscape pattern, urbanization, spatial metrics.

The conversion of Earth's land surface to urban uses is one of the most irreversible human impacts on the global biosphere. It drives the loss of farmland, affects local climate, soil, environmental pollution, fragments habitats, and threatens biodiversity (Li et al., 2011; Seto et al., 2011).

By integrating aerial photographs and spatial metrics, this study explored the spatio-temporal dynamics and evolution of land use change and landscape patterns in response to the urbanization process, from 1990 to 2015, on Cosenza and Rende municipalities, in southern Italy (Guagliardi et al., 2016a). Hence, assembling retrospective urban land use databases that reflect several decades of change, it was possible monitoring the effects of urbanization on the landscape in a timely and cost-effective way.

Changes of landscape patterns in the study area were detected by landscape metrics, which quantify and categorize complex landscape into identifiable patterns and reveal some properties that are not directly observable (Weng, 2007; Ricca & Guagliardi, 2015).

The results indicated that the urbanization process has caused significant land use changes and urban growth and, consequently, given rise to substantial impacts on the landscape patterns. Moreover, the contaminated environment of Cosenza and Rende, connected with the expansion of urban area, was already analysed by Guagliardi et al. (2013; 2015; 2016b), who attested how the anthropogenic sources have changed the natural background in soils.

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Morphological abnormalities of planktonic foraminiferal tests in the SW Pacific Ocean over the last 550 ky

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Keywords: planktonic foraminifera, abnormal test, environmental stressors, interglacials, SW Pacific.

The research focuses on the occurrence of morphologically abnormal specimens of planktonic foraminifera observed over the last 550 ky in IMAGES core MD 97-2114 (East of New Zealand, SW Pacific).

Abnormal tests occurred throughout the entire record in all the morphospecies characterising the assemblages but were relatively rare, with percentages not exceeding 1.5% of the total assemblage. No mass abnormality events were found. A range of malformations were observed from slight deformity with smaller or overdeveloped chambers to more severe deformity, with misplaced chambers, distorted spirals or double tests forming twinned individuals. They exhibited several different categories of morphological abnormalities, even within the same sample. Test abnormalities were most abundant in the morphospecies *Globorotalia inflata*, *Globigerina bulloides* and *Orbulina universa* and were characterised by a long-term decreasing trend up core with an alternating % abundance pattern at the glacial to interglacial scale between MIS 14 to MIS 8, recording the highest percentages during the interglacials.

Normalised total abundance and abnormal abundance curves co-varied very closely for *G. bulloides* and *O. universa*, but for *G. inflata* two opposing excursions were observed during MIS 13 and MIS 6 which may be linked to water column states. Although abnormal numbers were proportionately low, there appears to be a "natural" background number of malformations in the *G. inflata* population through time. There was no relationship between volcanic ash production and test abnormalities.

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Palynology from off-sites and on-site contexts as a tool for the assessment of long-term human impact

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Keywords: palynology, archaeological sites, Holocene.

The history of vegetation cannot be separated from the history of land-use in the Mediterranean basin. Therefore, when we talk about long-term ecosystem changes we often have to talk about cultural landscapes in the last millennia (Mercuri, 2014).

Marine and lake cores are off-site by definition and classically they record vegetation history and climate over very large regional areas. In the on-sites, i.e. archaeological contexts, human presence is obvious. Pollen preservation can be poor, human transport dominates and thus cultural variables strongly influence pollen spectra. Far from being a problem, this taphonomical peculiarity is crucial to explore human behaviour and cultural aspects of plant exploitation.

A set of palynological/archaeobotanical research has been carried out in the last decades (https://brainplants.unimore.it/; Mercuri et al., 2015). The research joins multidisciplinary archaeological study to palaeoenvironmental – ecological approach, with focus on the Italian peninsula and its impressive prehistoric and historic archaeological heritage.

The general indication given by off-site/on-site spectra is that forest cover near archaeological sites was generally low. By studying different contexts, however, we find that not only vegetation history under climate changes can explain the forestation curve and trend of the main taxa. For example, pollen percentages of 'cultural trees' Olea, Juglans and Castanea increase also favoured by human selection in off-site cores. In archaeological sites, that are by definition locally affected by human presence and activity, the pollen grains of Olea are ubiquitous in Southern Italy, while those of Juglans and Castanea are more common in central and northern Italy.

Moreover, seven taxa are characteristic of on-site spectra and important to assess land-use and human impact. The ubiquitous are Artemisia, Centaurea, Cichorieae, Plantago, while the cereals, Trifolium type and Urtica are common. Examples of high-resolution studies include the pollen sequence from the Terramara Santa Rosa di Poviglio, dated to the Middle-Recent Bronze Age in Northern Italy (Cremaschi et al. 2016).

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Last Interglacial climatic and environmental variability from continental carbonates (speleothems and lacustrine sediment): a coherent framework from central Italy sites

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Keywords: Last Interglacial, continental carbonates, central Italy.

The Last Interglacial, roughly matching the Marine Isotope Stage 5e, is the closest interglacial to the present one and one of the best documented in different polar, marine and terrestrial archives (Govin et al., 2015 and references therein). Although boundary conditions (i.e., orbital configurations) are different from the Holocene, this makes the MIS 5e well suited to study atmospheric–oceanic–terrestrial linkages occurring during warm intervals. However, there are few chronologically well-anchored continental records documenting the MIS 5 climatic history over the Mediterranean (e.g. Drysdale et al., 2005; Vogel et al., 2008; Regattieri et al., 2014), an area which has been shown to be particularly sensitive to global changes (Giorgi & Lionello, 2008).

Here we present three different multiproxy records from continental carbonates (speleothem and lacustrine sediment) from mountain sites along the Apennine chain, central Italy, all having an independent, radiometric chronology. The presented study cases give a coherent framework of environmental and hydrological variability which can be compared with regional and extra regional records, in order to understand how hydrological patterns in the Mediterranean are modulated by the interactions between different components of the climate system, with a particular focus on respective influences of North Atlantic oceanic circulation and sub-tropical low latitudes atmospheric patterns.

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New geoarcheological investigations at Scaloria Cave: some preliminary results.

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Keywords: Micromorphology, Middle Neolithic, Speleothems.

The cave is located at about 1 km NE of Manfredonia (FG). The entrance is about 45 m above present sea level, it overlooks the actual coastal plain. Today Scaloria is a part of a widest karstic system. Scaloria cave was accidentally discovered in 1932 during the construction of an underground aqueduct. The first archaeological excavations were performed in 1978 by University of Genoa and Los Angeles, and then again in 2007 and 2008 (Elster et. al., 2016). The Cave provided shelter from the late Upper Palaeolithic throught the Neolithic and housed an extensive Neolithic cemetery where the fragmented and commingled burial layer indicates complex secondary burial rites (Robb et al., 2015). The geoarchaeological study was undertaken using a descriptive approach of the inner cave with its calcareous concretions and so far has included a stratigraphic study of the site by micromorphological analysis (Rellini et al., 2016).

Most recently, in 2013 an micromorphological sampling programme was implemented to investigate the stratigraphic succession of the cave. High priority goal is an understanding of the relationships between settlement and environmental dynamics, paying special attention to assessment of cave use during the Middle Neolithic in Puglia (Italy). The micromorphological study sheds new light on the issue of Scaloria Cave occupation during the Neolithic while the observations on speleothems (fabrics and morphology) offer more accurate information about the earthquakes that caused the Scaloria cave to open or to close.

Elster E.S., Isetti E., Robb J. & Traverso A. (Eds.). 2016. The Archeology of Grotta Scaloria, Cotsen Institute of Archaeology Pres, Los Angeles (CA).

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Micromorphology of two archeological site in the Liguria Region and their paleoclimatic implication

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Keywords: Middle Paleolithic, Middle Bronze Age, Micromorphology, clay illuviation.

Micromorphology is the microscopic observation of undisturbed soil and sediment samples. It has been used in archaeology since the late 1980s for the study of site formation processes. In this work, we present some examples of the potential of soil micromorphology for palaeoenvironmental studies in archaeological contexts. We provide examples from two Ligurian prehistoric sites where micromorphological analyses enrich the discussion on environmental changes: Tana di Badalucco and Renesso di Savignone. Tana di Badalucco is a cave site in the Maritime Alps (valle Argentina) and lies in the territory of Pigna municipality. The cave appears to be a relict of syngenetic passage developed along bedding plane. The cave fill is characterized by two unit: an upper unit composed mainly by coarse sub-angular limestone fragments with bones and a deeper unit composed of rubified clayey material. They are representative of the transition between Middle and Upper Paleolithic both from cultural and paleoenvironmental views (Del Lucchese et al., 2013). The data supported the hypothesis of various soil formation stages under varying climatic conditions. Micromorphological observations show that strong pedogenesis (rubification, clay illuviation and hydromorphism) has affected the deeper unit under warm and humid interglacial-like conditions, while the scarce alteration degree, the occurrence of $CaCO_3$ and cryogenic features in the upper unit demonstrates that it was subjected a short period of pedogenesis under drier and colder climatic conditions which were presumably related to a periglacial environment during the LGM.

Renesso di Savignone is an open air site in the Ligurian Apennines. The studied deposit, dated to Middle Bronze Age, is composed of reworked material from the surrounding area. The sediments contained numerous pieces of charcoal and several pottery ceramics, including fragments of *tuyères* (Bianchi et al., 2015). We apply the method of micromorphology, coupled with SEM microanalysis in order to identify possible metallurgical contamination. The analysis shows that material represents a metallurgical debris. Backscattering SEM images and EDS analyses of characteristic areas reveal minor amounts of Cu, Zi and Pb, while micromorphology show typical features related to high temperature burnt material as well as fragmented and vitrified quartz grains. Moreover undisrupted clay infillings have been described in the charcoal and quartz grains pores. This evidence indicated that the illuviation was younger than the Middle Bronze Age material. Therefore, this later stage of clay might have occurred during the a warm/wet transitional period of Holocene after the Middle Bronze Age (Subboreal).

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How *not* to manage land: a case study from a reclaimed coastal area in Campania Region (southern Italy)

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Keywords: Volturno River, Campania, coastal area, reclamation intervention, land-use changes, GIS.

Crossed by the Volturno river, the coastal area of northern Campania is comprised of a wide floodplain with several depressions from drained marshes and a delta formed mainly by beach ridges.

The present-day geomorphological setting has been inherited by the sedimentary evolution following the Holocene glacio-eustatic sea level rise, after the Last Glacial Maximum. As for other Italian alluvial coastal plains, 6.5 ky cal BP a coastal progradational phase established, leading to the formation of a wave-dominated delta system, with flanking strandplains forming beach-dune ridges partially enclosing lagoon-marshy areas. Beach and lagoon environments persisted up to 2 ky cal BP. The remnant of the area previously occupied by the larger wetland that formed along the coastal zone at the mouths of the Volturno river during the last thousand years, nowadays lies at an elevation between 0 and -2 m with respect to the present sea-level.

Historical analysis coupled with a cartographic restitution in a GIS environment has produced documentary evidence of the geomorphological evolution of the area since the end of the XVII century, when - during the Spanish vice-kingdom – it was subjected to major land reclamation. The development of agriculture and farming on reclaimed land promoted urbanization and increasing landscape fragmentation. The peak was attained between the 1960s and the 1990s, when landscape pattern structure increased in complexity with major alterations of alluvial channels and of the deltaic environment, and retreat of the coastline.

In the last two decades, human activities played a great role in changing coastal footprint by increasing urbanisation, transport networks and tourist sites, together with extensive sea defence and coastal protection works. The related impacts include the urban and industrial waste disposal along the river and canals, as well as unlawful damping and quarries, severe coastline erosion, floods, saline intrusions, and pollution of the groundwater and coastal waters. As a consequence, a landscape fragmentation increased significantly between the 1960s and the 1990s.

The overgrowth of the urban areas to the sea, coupled with intensification of agricultural and tourism activities, resulted in the loss of high quality ecosystems such as the humid coastal setting, the lacustrine/marshy back-dune area and, in most cases, also the beach-dune system in a fluvio-deltaic Natura 2000 network site in northern Campania.

On the whole, the integration of landscape analysis and historical information improved our understanding of spatial temporal dynamics of a coastal sector of the Campania Plain, of considerable interest from the point of view of both scientific and socio-economic development. The study highlights also the importance of an interdisciplinary approach in land management. The outcomes of this research will be beneficial to society for better decision making over coastal area applications, in a sustainable manner.

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Chronology, modalities of the last deglaciation, and Schmidt hammer exposure-age dating of the Splügenpass area (Italian Alps)

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Keywords: Schmidt hammer exposure-age dating, Splügenpass, Alps, Lateglacial, Holocene.

Within the framework of scientific researches related to geomorphological and climatic evolution of the Alps during Lateglacial and Holocene, only few studies were carried out on periglacial sedimentary terrains. In order to reconstitute the palaeoenvironmental history of the alpine periglacial domain, this research had focused on the morphostratigraphy of periglacial and glacial landforms of the Splügenpass region (transnational pass between Switzerland and Italy). The surface dating was performed with the analysis of Schmidt hammer rebound values. The joint utilisation of palaeogeographical method, which allows the reconstruction of past glacial and rock glaciers extension, and of Schmidt hammer exposure-age dating (SHD), provided an age-calibration curve of rebound values and relative chronologies with high temporal resolution. Schmidt hammer rebound values were calibrated thanks to two historical mule tracks, dated respectively from the Roman Epoch (1.65 ka cal BP, and from the Late Middle Ages (0.7 ka cal BP). Thanks to SHD, it was possible to establish a chronology of the Lateglacial glacier retreat and to date rock glacier and talus slope development. In a chronological point of view, the results show that Splügenpass was ice free since 15.8 ± 2.6 ka cal BP, whereas the Splügenpass rock glacier started its formation during the Lateglacial Interstadial (the minimal age of the front is of 12.6 ± 2.6 ka cal BP). The SHD age-calibration based on historical surfaces of known age highlights a non-linear behaviour of surface weathering along the Lateglacial and the Holocene. The investigations will also improve the knowledge of the potential use of SHD for numerical-age dating in alpine geomorphological studies, a field of research that is currently rapidly developing and that can be an alternative to Cosmogenic Nuclides dating in the understanding of complex glacial-periglacial-paraglacial landsystems.

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Lake Ohrid (FYROM/Albania): palynology of the last interglacial

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Keywords: Lake Ohrid (Macedonia/Albania), pollen analysis, climate change, vegetation reconstruction, MIS5e

Lake Ohrid (Albania/FYROM) is located in the north-eastern Mediterranean region at 693 m a.s.l. The lake is considered the oldest lake in Europe and an important hotspot of biodiversity, included in the UNESCO "World Heritage Site" list since 1997, as it hosts over 210 endemic species.

The lake sediments are a precious archive of climate change, biodiversity, volcanic ashes, and tectonic activity. During a recent drilling campaign (spring 2013) mostly financed by the ICDP (International Continental Scientific Drilling Program) and carried out in the frame of the project SCOPSCO (Scientific Collaboration On Past Speciation Conditions in Lake Ohrid), six parallel cores have been collected from the depocenter of the lake and a composite sequence (DEEP), with an impressive depth of 569 m, spanning at least the last 1.2 million years, was obtained.

Pollen analysis of the top 200 m of the sequence have revealed that this portion of the record, covering the last 500,000 years and at least five glacial/interglacial cycles, shows alternations between forested and non-forested periods in conjunction with a progressive change from cooler and wetter to warmer and drier conditions during interglacial and glacial periods (Sadori et al., 2016).

Here we present the preliminary high-resolution (roughly one sample every 400 years) pollen results of sediments ascribed to the last interglacial, the Eemian, corresponding to marine isotope substage 5e (MIS5e). The period, showing a certain variability, has been multidisciplinary investigated and its chronology was carefully tuned (Francke et al., 2016; Zanchetta et al., 2016).

The preliminary data revealed that the surroundings of Lake Ohrid during the Eemian were featured by mesophilous communities prevailing on montane ones and by less Mediterranean taxa than expected. Forests were mainly characterized by expansion of *Q. cerris* type and *Q. robur* type together with *Abies* and *Pinus*.

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The fire history in the northern and eastern Italy as a result of climate, vegetation and human impact: the case study of the marine core RF93-30

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Keywords: microcharcoals, marine core, Holocene, fire events, landscape transformation.

The relationships between landscape transformation and fire history are not completely understood because of the complex interaction of climate, vegetation and human activity during the Holocene. Fires can be natural, when biomass and weather conditions are suitable to trigger them, or anthropic when humans use fire for domestic and agricultural activities (Sadori et al., 2015).

In this study we show the first analysis of microcharcoals deposited in marine sediments.

The marine core RF93-30, 627 cm long, was studied in the PALICLAS project (Guilizzoni & Oldfield, 1996) and was collected 18 km north of the northern coast of the Gargano promontory, in southern Italy (Lat. 42°40'01'' N; Long. 15°40'03'' E) by the CNR-IGM team from Bologna.

Oldfield et al. (2003) dated the sediments using both palaeomagnetism and radiocarbon dates performed on benthic and planktic foraminifera (at 527 and 599 cm). Mercuri et al. (2012) reconsidered the original chronology to propose an up-dated age-depth model over the last 7000 years. The presence of microcharcoals in pollen samples was taken as an evidence of fire. Fires should have occurred in the basin of origin of the sediments, from the Po valley to the central and eastern regions. Our hypothesis is that the size of microcharcoals may be related to the distance of the fire on lands. Our results show that five major fire events (related to high concentrations of microcharcoals) occurred from the mid-Holocene to Modern Age. The two oldest events, at ca. 6723 cal yrs BP (4773 BC) and at ca. 5427 cal yrs BP (3477 BC), were probably related to a progressive aridification of climate. A third event was found at ca. 2240 cal yrs BP (290 BC), and took place probably near the coast because of the large size of microcharcoals. Finally, high concentration of microcharcoals was present in recent times, at ca.117 cal yrs BP (1833 AD) and at ca.96 cal yrs BP (1854 AD).

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Palaeoclimatic signals from ODP Site 976 (western Mediterranean): an integrated isotope and bio-stratigraphic record of MIS 19

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Keywords: MIS 19, pollen, isotopes, calcareous plankton, astrochronology, Alboran sea.

We present here the result of an integrated stratigraphic work where pollen, calcareous plankton and oxygen isotopes records from a single section combine to climatically investigate marine isotope stage (MIS) 19 in the western Mediterranean. The study focuses on the Ocean Drilling Program (ODP) Site 976, cored in the Alboran sea (~10 km East of Strait of Gibraltar) during the Leg 161. Ninety-three samples were picked from the 200.57-209.77 m composite depth (mcd) interval to obtain a high resolution along about 20 ka covering most of MIS 19. The palaeoclimatic proxies show comparable and almost synchronous orbital scale variations such as the interglacial onset and a series of short cooling events including sub-stage 19b. Such variations are robust climate-stratigraphic markers in the Mediterranean region and abroad because of their systematic nature and their impact on a wide set of proxies. On the other hand, some short-term fluctuations in biotic spectra are not clearly recorded in the isotopic curves, possibly pointing out local environmental signals.

The new stable isotopic record we obtained permits to establish a precise chronology by means of tuning with global calibrated curves. Based on the analyses of the abundant, well preserved terrestrial and marine assemblages we propose a detailed reconstruction of the past terrestrial vegetation and oceanographic conditions in that sector of Mediterranean that will contribute to enrich the current available palaeoecological and paleoclimate data set. Furthermore, we stress the direct land-sea correlations which are possible by integrating pollen and calcareous plankton since this has implications in the understanding of the differential impact of climate on geographically contiguous environments.

Finally, due to the similarity in term of orbital configuration of this time period with the Holocene the two interglacials are compared.

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Holocene climate variability from Rio Martino Cave (Western Alps, northern Italy)

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Keywords: Stable isotopes, speleothems, magnetic susceptibility, remanence intensity.

The Alpine region currently experiences complex climatic conditions and presumably it was the case for the Holocene. For depicting the climatic evolution of the western sector of the Alps, several flowstone cores were retrieved from Rio Martino Cave (Piemonte, Northern Italy, ca. 1530 m a.s.l.) in the upper Po Valley, where the climate is dominated by North Atlantic synoptic systems (Efthymiadis et al., 2007). U/Th dating of flowstones indicates a phase of deposition starting at the beginning of the Holocene. Two cores were intensively studied using a multi-proxy approach (stable isotopes and rock magnetism). The $\delta^{18}O$ record spans from ca. 10 ka to 0.5 ka and shows substantial variability, which is interpreted as changes in rainfall $\delta^{18}O$ recharging the cave catchment. Variations in $\delta^{13}C$ instead are interpreted as reflecting the degree of soil development. A long-term trend in $\delta^{18}O$ is apparent, with relatively low values persisting from the commencement of deposition until ca. 6 ka. From 6 to 3 ka the $\delta^{18}O$ increases gradually before decreasing again from 3 ka onward. $\delta^{13}C$ shows a good degree of correlation with $\delta^{18}O$. Superimposed on this trend are numerous centennial-scale oscillations which may reflect alternating periods of drier and wetter conditions. Both stable isotope records and magnetic susceptibility and remanence intensity, which mainly depend on the detrital content inside the speleothem, show an interesting similarity with increases in the frequency of floods as recorded by recent compilations of lake records (Wirth et al., 2013).

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Climatic conditions from northern Tuscany during late Etruscan and Roman times as revealed by speleothems: insights into the Anthropocene

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Keywords: Roman, paleoclimate, floods, Apuan Alps.

Human activity has been a geologically recent, yet profound, influence on the global environment (Lewis & Maslin, 2015) and the Holocene has witnessed the transition from nature-dominated to human-dominated shaping of Earth landscape and its atmosphere (Messerli et al., 2000). This switch has been neither regionally homogenous nor necessarily progressive. During this period the Mediterranean region was the cradle for some of the world's oldest civilizations. During the same period, there were important climatic changes that along with the human activity transformed the landscape in a way difficult to disentangle (e.g. Zanchetta et al., 2013). For better understanding the different roles of climate and human activity it is necessary to start from the analyses of restricted areas where archeological, palaeocological, geomorphological and paleoclimatological data can be merged in a single "holistic" view (e.g. Sadori et al., 2016). Here, we present high resolution paleoclimatic data from speleothem from Northern Tuscany and archeological data which show the different response of the environment between late Etruscan to Roman times. In particular, during this period a significant increase in floods intensity and recurrence is recognizable at ca. 2000 yr cal BP, which is in agreement with archaeological evidences. However, the ability of Roman society to control the environment probably mitigates the impact of this climatic phase.

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Was the termination of the Holocene African Humid Period abrupt of gradual? Comparison of offshore and continental records and archaeological implications

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Keywords: African Humid Period, Sahara, Late Holocene, landscape change, adaptive strategies.

The Holocene African Humid Period (AHP) is a well-known climatic phase occurred between 15-5 kya triggered by the northward expansion of the African monsoon domains. The onset of the AHP and the climatic and environmental dynamics that marked this phase are relatively well known, thanks to a large number of studies carried out at many sites on a variety of archives for proxy data. Many details are also available for the human responses to landscape changes occurred in the Sahara in the AHP. On the contrary, mostly due to the lacking of well time-constrained and continuous stratigraphic sequences, contrasting hypotheses on the termination of the AHP exist. This occurred at c. 5 kya and is alternatively interpreted as abrupt or gradual. On one hand, the interpretation of the sedimentary record of a series of offshore proxies suggest an abrupt termination of the AHP that can be inferred by an immediate increase in the terrigenous input to the Atlantic Ocean. On the other hand, the investigation on several inland palaeohydrological archives, which are related to the physical functioning of the surfaces, shows a more complicate scenario of chronologically differentiated reduction of water availability occurred over a millennial-scale period. The response to the reduction of monsoon precipitation therefore occurred on the basis of the physiographic settings of each region and local threshold-like behaviour of hydrological reservoirs. In both cases, the major trend in recent archaeological literature links the transition to aridity to the collapse of civilizations, abandonment of regions, and demographic drops. In spite of data from selected - yet still few - contexts, this deterministic view has often been assumed in the archaeological reconstructions of past cultural trajectories in the Sahara, overshadowing local developments, cultural adjustments, and signs of continuity in human occupations. In this contribution, we will review the available literature on the issue of the termination of the AHP, considering more carefully proxy data, which more directly record changes in ancient landscapes; moreover, we would like to offer a different perspective on the effects of the Mid-Holocene climatic transition on Saharan population and highlight their contribution on the late Holocene societal re-organization

SESSION S15

Polar region on a changing planet: learning from the past, exploring the future

CONVENERS AND CHAIRPERSONS

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The Antarctic paradox: sea ice extent and thickness trends during the last three decades

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Keywords: Antarctic paradox, sea ice, climate change, remote sensing.

In polar regions, ocean–atmosphere interactions are strongly influenced by sea ice and its thickness. Since satellite passive microwave observations became available in the 1970s, significant progress has been made in the study of snow depth and sea ice concentration/extent in these regions. Satellite observations collected in the last three decades show that Arctic sea ice has been reduced drastically while Antarctic sea ice has been stable or even increasing (slowly but to record levels). This expansion is at odds with general climate model results. These different behaviors in Arctic and Antarctic sea ice constitute a challenging paradox to be explained by the cryosphere community. While climate deniers claimed record Antarctic sea ice was a refutation of climate change, in reality it showed they could not fathom that the cryosphere and the Earth climate are complex processes which we are still trying to understand. In this framework the polar paradox is a key issue in climate science to be convincingly resolved, through appropriate accounting of controlling factors, in order to advance Earth system models to achieve projections with a significantly reduced uncertainty. A number of hypotheses have been proposed to explain the polar paradox: i) stratospheric ozone depletion may affect atmospheric circulation and wind patterns sustaining the Antarctic sea ice cover, ii) warm deep ocean currents are contributing to ice shelves melt thus shielding the surface ocean from the warmer deeper waters, iii) decrease in sea ice growth may reduce salt rejection and upper-ocean density to enhance thermohaline stratification, iv) Antarctica lacks of additional heat sources such as warm river discharge as is the case in the Arctic.Estimating what is happening under the sea ice surface, instead, turned out to be considerably more difficult. Recent studies using several satellite products (IceSat, Cryosat-2, SMOS) show that also sea ice thickness is drastically decreasing in the Arctic, while few studies have been provided about Antarctica. In this study we used the estimations provided by the SIT algorithm (Aulicino et al., 2014) including passive microwave satellite observations to demonstrate that no evidences of negative sea ice thickness trends can be detected in two of the most important regions of the Southern Ocean (i.e., the Ross and Weddell Seas), over the last two decades (1992-2015). We also show that these regions behave differently in the study period: a dipolar behavior is evident in the first decade of analysis (1992-2002) while not present in the following decade. Connections to the main climate indexes suggest that the study of regional scales is fundamental for a detailed comprehension of the Antarctic sea ice dynamics and evolution.

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Cenozoic glacial variation and landscape evolution in Antarctica: new insights from the continental record

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Keywords: Antarctica, Cemnozoic, glacial geology, Geomorphology, exposure dating.

Although Antarctica reached a polar position since 100 Ma, the oldest Cenozoic glaciers developed about 50 Ma ago (Early to Middle Eocene). Since at least 55 Ma and before the 34 Ma, following the most vigorous uplift phase of the Transantarctic Mountains, fluvial landsculpting was the main geomorphologic process active in denudating the Transantarctic Mountains. It is widely accepted that the global cooling registered at about 34 Ma (Eocene-Oligocene boundary) forced the shift fron green-house to ice-house condition on the Earth. Since then on, well identifiable relict landscape features and glacial deposits testify that the most widespread land-sculpting process was glacial erosion, due to the formation of temperate ice sheets expanding both on East and West Antarctica.

Well-developed relict alpine topography postdates the fluvial morphology also in northern Victoria Land, where a complex system of temperate glaciers was responsible for denudation until the Late Miocene. and polar environment endured since at least 7.5 – 8 Ma. The employment of multiple cosmogenic nuclides (^{10}Be, ^{26}Al, ^{21}Ne) constrains denudation rates which testify persistent climate stability of the Antarctic glacial system. Cold and dry hyperarid condition endured since at least 7.5 – 8 Ma. Complex glacial dynamics are well-worn in the coastal area as well as at the internal margin of the ice sheet. New results provide valuable insights into the reconstruction of the major Plio-Pleistocene glacial events recorded in Victoria Land and the identification of significant relationships with other Antarctic regions.

During the Last Glacial Maximum (MIS-2), the Antarctic ice sheets and their fringing ice-shelves expanded onto the continental shelf. Marine based ice inundated coastal areas up to 400-500 m above present sea level. The glacial retreat that occurred after the LGM was accompained by marine incursion and the subsequent isostatic rebound that led to the formation of raised beaches and allowed Adélie penguins and Elephant seas to re-occupying coastal areas.

The linkages between glaciers and other elements of the Antarctic system, the timing of their reaction to the same environmental stress, and the mechanisms involved therein, are key points for understanding the mechanisms forcing global changes occurred in the past and for future predictions on climatic and environmental changes, with particular attention to sea level variations for anticipating their feedback on inhabited lands.

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Crustal heat transfer in the Antarctic glaciers: From 1D- to 2D-multiphysics numerical modelling

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Keywords: glacial system, heat transfer, numerical modelling.

The glacial systems is highly sensitive to environmental conditions, global climate changes as well as to any other endogenous/external event that may affect energy balance altering its behaviour. During last decades polar regions are experiencing fast and deep changes, as still now debated in the scientific community. The present work focused on preliminary result of a multiphysics numerical modelling planned in the frame of the PNRA projects – Line B. More in particular, a 1D modelling of pure conductive heat transfer pointed out the role of several factor in crustal heat transfer and its effects of thermal regime of East Antarctic glacial system. The case study of northern Victoria Land (Antarctica) glacial system is here presented, i.e. a key site for investigating the amplitude of past ice volume variations in the East Antarctic Ice Sheet (EIAS), including a wide sector of the Transantarctic Mountains and the Mt. Melbourne Volcanic Province. Based on geo-thermometric data (Armienti & Perinelli 2010) combined with thermal properties of rock materials, a multi-parametric sensitivity analysis was performed, assuming a stationary and conductive geothermal heat flow, varying thermal parameters and stratigraphic profiles, i.e. considering different thickness for the different proportions of the continental crust representative of different geodynamic context. No shallow thermal perturbation due to volcanic systems was modelled. This model, took into account a crustal heat flux of 120 mW/m^2, typical value of rift zone and specific for the Victoria Land Basin. In addition, we considered a sensitivity analysis to the ice thickness of the glacial system up to 800 m, according to reconstructed Pleistocene EAIS variations. The modelling results highlighted a main contribution of regional heat source and ice sheet thicknesses on the thermal regime of the upper crust and valley slopes respect to geometrical and rock's thermal parameters. These outputs lead also to assume a predominant deep origin in thermal perturbations of glacial system focusing in addition the effects of local anomaly due to ice masses. The obtained results will be scaled to selected glacial valley, applying the outputs of 1D thermal model as thermal conditioning of a 2D Thermo-mechanical model in order to assess the sensitivity of the system to geothermal heat flux and define possible thermo-mechanical interactions between bedrock and ice masses focusing on stress-strain effects on the kinematic of the glaciers. The so defined models will consider available data as: i) thermal properties of valley slope rocks; ii) geologic and geomorphologic reconstruction of the glaciers; iii) heat flow from the bedrock representative of different geodynamic context, as well as iiii) thermal conditions on the ice mass.

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Sediment, current and bottom morphology: the right partnership to understand present and past environment dynamics. The central-western Ross sea case

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Keywords: Ross Sea, Antarctic Bottom Waters, circulation model, sediment box cores, morphology, seismic sec

The Ross Sea margin is a key area of the Earth System where the southern branch of the Ross Gyre, carrying the warm CircumPolar Deep Water (CDW), enters the continental shelf and mixes with cold shelf water. The upper layer mixes with the Antarctic surface water modifying its caracteristics, while the lower layer interacts with the outflowing cold and dense Ross Sea Shelf Water forming the new Antarctic Bottom Waters. The overflow and the downslope flow of these denser bottom water masses occurs in few localized areas. The eastern part of the shelf is characterized by the outflow of the cold Ice Shelf Waters (ISW), while the western part characterize the overflow of the High Salinity Shelf Waters (HSSW). Along the western Iselin Bank CDW rises and encroaches the shelf edge, above the Ross Sea Bottom Water. The mix of different water masses is influenced by the seabed morphology. Here we propose a study that combines the simulations of a general circulation model, seabed bathymetry, seismic sections and sediment box cores, with the aim to investigate the influence of warm oceanic water intrusions onto Last Glacial Maximum (LGM) ice grounding line retreat. The study area is the shelf margin around the Iselin Bank, a structural high of the continental crust that represents a large obstacle for the currents flowing to the west under the influence of the Coriolis forces.

Sediment mounds and drifts recognized on the base of sismic profiles characterize the morphology around the Iselin Bank. While some of these features are buried and inactive, others characterize the present sea floor and can thus document variability in bottom current flow pathways since the early Miocene. The continental slope to the east of the Iselin Banks is characterised by gullies or incisions originated by meltwater activity at the end of the LGM, together with deep canyons, slide scars and gravity flow deposits. This sector is a key area to investigate the advances and retreats of the WAIS. Instead, the sedimentary sequences recovered in the semi-closed basin at the west side of the Iselin Bank provide stratigraphic information concerning the EAIS extension within this sector, during the Quaternary glacial and interglacial cycles.

ROMS is the General Circulation Model used to reconstruct the currents and the thermo-haline 3d fields based on hydrographic measurements acquired during a decade of PNRA CLIMA project and the January 2001meteo forcing. We will show speed, density, temperature and direction of the present bottom current flowing along and down-slope at different depths and their correlations with the sea floor morphogies as well as the surficial sediments studied are consistent with this present current's characteristics. The box-core's sediments, from the LGM to the Present day, the seismic profiles for older situations (since late Miocene) in conjuction with the dynamic field will be used to have a first estimate of the past main pathway of the Ross Sea Bottom Water.

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Integrated sedimentology and micropaleontology for the study of the deglaciation post LGM in the south-western Svalbard slope (Arctic Ocean)

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Keywords: Barents Sea, sedimentology, microfossils, palaeoceanography, paleonvironment, Late Quaternary.

The north-western continental margin of the Barents Sea represents the only gateway for deep-water masses moving between the North Atlantic and the Arctic Oceans. On this respect, the western Svalbard margin, located on the eastern side of the Fram strait, represents a key area to study the paleoceanographic variation of the West and East Spitsbergen currents.

Integrated sedimentological and micropaleontological analyses on calcareous nannofossils, diatoms, planktonic and benthonic foraminifera and clay mineral assemblages have been performed on three sediment cores, collected during the EGLACOM and CORIBAR projects from the Storfjorden-Kveithola depositional system (NW Barents Sea), to reconstruct the paleoceanographic and paleoenvironmental evolution after the Last Glacial Maximum.

The lithological sequence and the magnetic susceptibility are consistent between the EGLACOM and CORIBAR cores. The recovered cores contain an expanded sedimentary sequence that includes continuous Holocene interglacial sediments.

The microfossils are scarce in the lithological units representing the deglaciation after the LGM, and become more abundant in the Holocene sequences that record a clear upswing of the North Atlantic Current (NAC) strength. Nevertheless, the benthic assemblage is indicative of non-permanently ice-covered conditions since about 16 cal ka BP.

The planktonic microfossil distribution patterns are coherent with the trend of smectite content in the clay mineral assemblage that is mainly transported by the NAC, therefore high contents are associated to a vigorous current (Junttila et al., 2010).

The nannofossil assemblages during the Holocene, are dominated by *Emiliania huxleyi* (< 4 µm), confirming the climatic amelioration. The diatom assemblages are dominated by *Chaetoceros* resting spores, related to stratified waters in association with ice melting at the beginning of Holocene. The presence of the diatom *Coscinodiscus* spp. and a more diversified planktonic foraminiferal assemblage, with *Neogloboquadrina pachyderma* (s), *N. incompta* and *Globigerina bulloides*, indicating subpolar conditions, confirm the onset of warm environmental period that were associated to the Holocene Thermal Maximum. The benthic foraminiferal assemblage here contains *Cassidulina reniforme*, *C. teretis*, *Islandiella helenae/norcrossi*, *Melonis barleeanum* and *Cibicidoides wuellerstorfi*. The significant occurrence of small taxa, such as *Stetsonia horvati*, during the middle-late Holocene suggests a condition of low productivity and limited flux of organic matter to the sea floor. The abundance of agglutinated species, corresponding to high percentage of benthic foraminifera fragmentation, indicate aggressive bottom waters and, could suggest the influence of cold, salty and dense waters, coming from the shelf area.

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Reconstruction of geomagnetic paleosecular variation for the last 16k years, from the Kveithola trough mouth fans, on the continental margin of northwestern Barents Sea

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Keywords: Paleomagnetism, Barents Sea, Kveithola trough, Last deglaciation.

In the last decades, in order to understand the variability of the geomagnetic field several geomagnetic paleosecular variation (PSV) for the past millennia, have been reconstructed from paleomagnetic and archeomagnetic data. In this scenario, PSV data from the Artic region could be of critical importance for geomagnetic field models. We report high-resolution results from paleomagnetic and rock magnetic analyses carried out on three sediment cores collected in glaciomarine silty-clay sequences from the continental shelf and slope of the Kveithola trough-mouth fan, on the continental margin of northwestern Barents Sea. This investigation has been carried out in the framework of the PNRA project CORIBAR-IT, with the general aim of defining the timing and the paleoenvironmental changes linked to the last deglaciation. The rock magnetic analyses indicate that all the analyzed cores show constantly good paleomagnetic properties. The results are very encouraging in terms of definition of high-resolution correlation between the cores and definition of PSV trends. We compared paleomagnetic inclination, declination and relative paleointensity curves with those expected at the location of analyzed core according to the global Scha.dif.14k PSV model, and found a remarkable match between the curves. Moreover, we point out a high-resolution correlation with the previous palaeomagnetic and rock magnetic trends obtained from other cores collected in the surrounding area and analyzed within former SVAIS and EGLACOM projects. The new paleomagnetic and rock magnetic data allowed to refine the reconstruction of geomagnetic field variation at 75°–76° northern latitudes during the last 16 ka. These data provide an original chronological framework for the sedimentological and the palaeoenvironmental evolution along an E-W transect from the continental shelf to slope in the NW Barents Sea during the main climatic pulses of glaciers fusion and retreat.

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Interannual variability of the Ross Sea shelf waters and correlation with climate indices

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Keywords: Southern Ocean, Ross Sea, interannual variability, shelf waters, climate indeces.

A multitude of observations confirm that the polar regions are the fastest and perhaps the most dramatically changing areas of the planet.

In few areas around Antarctica is formed the Antarctic Bottom Water (AABW), the densest and coldest water that occupies the bottom layer of the world ocean. The production of AABW plays a major role in determining the strength of the global Meridional Overturning Circulation and, therefore, is an important element in the ocean's contribution to the global climate.

Observations within the Southern Ocean's Pacific sector indicate a decadal trend of reduced salinity of the shelf waters (Jacobs et al., 2002; Jacobs & Giulivi, 2010; Budillon et al., 2011), that are precursor of the AABW. A change of the AABW properties, related to the freshening of this waters, has been observed in the Australian-Antarctic Basin (Shimada et al., 2012).

Strong changes in the thermohaline characteristics of the Ross Sea shelf waters are documented using CTD data, and moored time-series collected since 1995. In Terra Nova Bay polynya, in the western sector of the Ross Sea, the salinity of the High Salinity Shelf Water (HSSW) decreased of 0.08 in 17 years. Along the Ross Ice Shelf the benthic layer freshened about 0.02 from 1995 to 2006 end 0.07 to 2012. While, In the central sector is evident a freshening of the HSSW of 0.04 from 1998 to 2006 and a strong reduction of the Ice Shelf Water presence.

Our analyses showed that the NINO3.4 and the SAM indices are strongly correlate with shelf waters temperature anomaly in the central sector. In this work we analyzed the atmospheric patterns characterizing the different index phases and their possible impacts on the shelf water formation and on the Ross Sea capability to ventilate the bottom layers.

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Past and present sedimentary dynamics in the Ross Sea: a multidisciplinary approach to study the continental slope

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Keywords: Ross Sea, continental slope, sedimentary dynamics, sediment core, seismic profiles, grain-size.&a

Past and present sedimentary dynamics in the ROSS Sea: a multidisciplinary approach to study the continental SLOPE (ROSSLOPE) is a PNRA research project developed from September 2011 until May 2016 which aims to investigate the present and past water circulation from sedimentary sequences of the outer shelf and continental slope to the West and East of the Iselin Banks (Ross Sea). These are the main overflow areas of present dense, cold water masses: the HSSW (High Salinity Shelf Water) to the West of the Iselin Bank, and the ISW (Ice Shelf Water) to the East of the Iselin Bank.

The study was done in three steps

- The construction of a database constituted by a) multibeam surveys collected during a lot of PNRA and NSF/USA geophysical cruises b) single-channel and multi-channel national and foreign seismic data available through the Seismic Data Library System c) PNRA sediment box cores and gravity cores collected on the outer shelf, slope and rise areas of HSSW and ISW outflow during several previous cruises.
- The collection of new geophysical data and box cores and cores during three cruises on board the IB/RV ARAON (KOPRI-Korea, 2013), R/V Italica (2014), and IB/RV ARAON (2015).
- Data processing and comparison with shelf data.

Data processing based on multidisciplinary analyses (geophysical, textural, geochemical, mineralogical, micropaleontological, and paleomagnetic and rock magnetic analyses) allowed us to identify the main factors that are conditioning and have conditioned the sedimentation processes in the study area during the glacial and interglacial periods.

Ice sheet evolutions: investigating the past to predict the future

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Keywords: Antarctic ice sheet evolution, Greenland ice sheet evolution, tipping point, paleoclimate.

Over the last decades, the Greenland ice sheet melting has increased dramatically. During the last two summers the surface melting did not occurred only along the margins but covered the entire glaciated area of Greenland. In conjunction of an exceptional El Nino (2015-2016), this year Greenland started to melt earlier than usual. In Antarctica, no surface melt occurs, however, the sea ice extent has increased rapidly over the last decade. The cause of this larger extent is now explained by the melting occurring under the ice shelves of the Antarctic ice sheet, which, by being fresher and colder than the surrounding ocean waters refreezes below the sea ice cover. Defining the tipping point of both ice sheets, i.e. the threshold above which the ice loss is irreversible, is crucial in order to predict the sea -level rise and its social and economical impacts. Past climate reconstructions show that mean global temperatures and greenhouse gas concentration were higher than today when Antarctica and Greenland started to glaciate. Investigating the past therefore provide hints on how much the ice sheets can resist under global warming.

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Analogue modelling of the influence of ice shelf collapse on the flow of ice sheets grounded below sea-level

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Keywords: Analogue modelling, ice shelf collapse, Atarctice.

The sudden breakup of ice shelves is expected to result in significant acceleration of inland glaciers, a process related to the removal of the buttressing effect exerted by the ice shelf on the tributary glaciers. This effect has been tested in previous analogue models, which however applied to ice sheets grounded above sea level (e.g., East Antarctic Ice Sheet; Antarctic Peninsula and the Larsen Ice Shelf).

In this work we expand these previous results by performing small-scale laboratory models that analyse the influence of ice shelf collapse on the flow of ice streams draining an ice sheet grounded below sea level (e.g., the West Antarctic Ice Sheet). The analogue models, with dimensions (width, length, thickness) of 120x70x1.5cm were performed at the Tectonic Modelling Laboratory of CNR-IGG of Florence, Italy, by using Polydimethilsyloxane (PDMS) as analogue for the flowing ice. This transparent, Newtonian silicone has been shown to well approximate the rheology of natural ice. The silicone was allowed to flow into a water reservoir simulating natural conditions in which ice streams flow into the sea, terminating in extensive ice shelves which act as a buttress for their glaciers and slow their flow. The geometric scaling ratio was 10^{-5}, such that 1cm in the models simulated 1km in nature; a velocity of PDMS of 1 mm/hr simulated natural velocities of 100 m/year. Instability of glacier flow was induced by manually removing a basal silicone platform (floating on water) exerting backstresses to the flowing analogue glacier: the simple set-up adopted in the experiments isolates the effect of the removal of the buttressing effect that the floating platform exerts on the flowing glaciers, thus offering insights into the influence of this parameter on the flow perturbations resulting from a collapse event.

The experimental results showed a significant increase in glacier velocity close to its outlet following ice shelf breakup, a process similar to what observed in previous models. However, this transient effect did not significantly propagate upstream towards the inner parts of ice sheet, and rapidly decayed with time. The process was also accompanied by significant ice thinning close to the grounding line. Models results suggest that the ice sheet is almost unaffected by flow perturbations induced by ice shelf collapse, unless other processes (e.g., grounding line instability induced by warm water penetration) are involved.

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Position of main ACC fronts south of New Zealand from satellite altimetry and XBT data in the period 1994-2015

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Keywords: Antarctic Circumpolar Current - ACC, Southern Ocean - SO, Altimetry data, Expendable BathyThermograph.

A long time series of XBT data collected during Austral summers and satellite altimetry data south of New Zealand are used to identify the positions of the main Antarctic Circumpolar Current (ACC) fronts and their branches from 1994 to 2015. The study area has been investigated since 1994 in the framework of the Climatic Long-term Interaction for the Mass balance in Antarctica (CLIMA), the Southern Ocean Chokepoints Italian Contribution (SOChIC) and the Marine Observatory in the Ross Sea (MORSEA) projects of the Italian National Research Program in Antarctica (PNRA). During these projects, in situ temperature sections of the surface layer (0-800 m) of the Southern Ocean along the track New Zealand-Ross Sea have been occupied almost every summer season by means of XBT.

The flow of the ACC is well known to be concentrated in several jets associated with fronts, or regions of strong horizontal gradients in water mass properties and sea surface height. These fronts are linked to particular water mass features, allowing simple criteria based on temperature and salinity to be used to locate them. In this study regional thermal criteria have been used for the detection of ACC fronts from in situ XBT data. The positions of ACC fronts from in situ XBT data agree with existing literature even if a slight increase in the standard deviation during last years is found and the indication of a southward trend in the positions of fronts is shown.

Moreover, satellite altimetry data provided by AVISO have been used to identify the positions of the fronts on the basis of specific dynamic height values usually associated to each front as well as through the location on the maximum Absolute Dynamic Topography gradient within a predetermined frontal region. Both altimetry-based methods allowed us to partially fill the gap between consecutive in situ measurements and offered different results. These positions have been compared with those determined from in situ data and finally results from the three identification methods are discussed.

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Seismic and satellite observations of calving activity at major glacier fronts in Greenland

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Keywords: Greenland, iceberg calving, satellite observ ation, seismic observation.

The interaction between oceans and large outlet glaciers in polar regions contributes to the budget of the global water cycle.

We have observed the dynamic of sizeable outlet glaciers in Greenland by the analysis of seismic data collected by the regional seismic network Greenland Ice Sheet Monitoring Network (GLISN) in order to find out correspondence in the glacier tongue evolution derived by the observation of satellite images.

By studying the long-period seismic signals at stations located at the mouth of large fjords (e.g. ILULI, NUUG, KULLO), we identify major calving events through the automatic detection of the ground flexure in response to seiche waves generated by iceberg detachments.

For the time spanning the period between 2010-2014, we fill out calving-event catalogues which can be useful for the estimation of spatial and temporal variations in volume of ice loss at major active fronts in Greenland.

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Tectono-metamorphic constraints on the evolution of an HT suture zone: insights from metasedimentary rocks of the Dessent Unit (northern Victoria Land, Antarctica)

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Keywords: northern Victoria Land metamorphism, Ross Orogen, high temperature mylonite.

The largest exposure of the Late-Precambrian to early Palaezoic Ross orogen is present in the northern Victoria Land, NVL, where three main fault-bounded litho-tectonic units occur (*e.g.* Federico et al., 2006): (i) the Wilson Terrane (WT) composed of low to high grade metamorphic rocks intruded by Cambro-Ordovician igneous rocks; (ii) the Bowers Terrane (BT) dominated by volcanites and sedimentary rocks affected mostly by low grade metamorphisms; (iii) Robertson Bay Terrane (RBT) made mainly by turbidites overprinted by very-low to low grade metamorphism.

The contact between the WT and the BT is marked by a highly tectonized belt, involving eclogite remnants (Ricci et al. 1996; Federico et al., 2006). In the central part of the Mountaineer Range the Dessent Unit (DU), characterized by alternations of amphibolites and metasediments (Capponi et al., 1988), marks this contact. Whereas mafic rocks are well characterized (*e.g.* Capponi et al., 1988; Scambelluri et al., 2003; Palmeri et al., 2012), very few data are available for metasediments (Capponi et al., 1988). We present a microstructural and petrographic study of DU metasediments (samples collected in past Italiantartide Expeditions). Our investigations demonstrate that the main regional foliation is related at least to a second tectonic event, since an older foliation is preserved within microlithons and intertectonic porphyroblasts. Moreover, evidence of upper amphibolitic to low granulitic HT mylonitic shearing has been detected. Finally, a late static growth of chlorite (and minor white mica) is widespread in most samples. Metamorphic constraints, obtained from selected samples with the aid of pseudosections and multi-equilibrium thermobarometry, indicate that most of the metasediments have been equilibrated in the P-T range of 650-700°C and 7-8 kbar, followed by cooling and decompression, compatible with results from the DU amphibolites (Palmeri et al., 2012). Interestingly, relicts of a previous granulitic stage, already reported for some DU amphibolitic rocks (Scambelluri et al., 2003), have been detected also in a metamarl sample. In summary, our results demonstrate that metasediments shared a similar history with the amphibolites, and give further constraints for the tectono-metamorphic evolution of the WT-BT suture zone revealing the occurrence of a high T shearing event.

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Long time-series of downward particle fluxes over Arctic and Antarctic continental margins

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Keywords: downward particle fluxes, time-series, polar regions.

The export of particulate organic carbon (POC) from the sea surface to the ocean interior is an essential part of the biological pump. The POC escaping the upper water column is delivered to the deep ocean where is in part remineralized. These sinks retain CO_2 for a relatively long period (decadal to millennial) compared with the epipelagic CO_2 residence time. Then, the recalcitrant fraction of organic carbon accumulates in marine sediments representing the long-term reservoir of biogenic material (millennial to geological time scale).

Vertical flux patterns have been extensively studied in the past 25 years by using sediment traps deployed in different regions of the Ross Sea, the most productive Antarctic region. More than 1000 sediment trap samples are now available from 23 Italian and US sites. Fluxes of OC and total mass are well correlated, implying that particle fluxes are dominated by biogenic debris. Annual OC fluxes to below 200 m average 4.4±3.3 g C m^{-2} yr^{-1}, which are significantly less than export fluxes calculated using short-term surface water mass balance approaches or Th isotope techniques, yet are higher than sediment accumulation rates. Furthermore, nearly all particle flux time-series show relative low sedimentation during the periods of high primary production in surface waters followed by enhanced sedimentation periods during late summer/fall. This high degree of decoupling between production and sedimentation is unusual if compared with records of Antarctic Peninsula and may represent low grazing rates. Furthermore, the OC fluxes are highly variable both seasonally and interannually. This high variability of export fluxes make it difficult to identify possible long-term trend and to reach firm conclusions.

On the contrary, the decrease of sea-ice extent and thickness in the Arctic in the past decades is statistically significant. At the same time, water temperatures in Fram Strait, west of Svalbard archipelago, exhibit an overall slight increase, even at 2500 m water depth of the central HAUSGARTEN site. Here, particle fluxes measured since 2000 reveal a general trend in decreasing POC fluxes. Starting from 2010, we have deployed sediment traps also in the Storfjorden continental slope. We found that the lithogenic fraction is the more abundant constituent. The highest lithogenic fluxes and coarse grain size of settling particles are measured in late winter–early spring. At the same time, pulses of the northward flowing west Spitsbergen current (WSC) are recorded. The WSC is probably able to resuspend and transport the sediments deposited on the uppermost slope. Finally, particle fluxes show the typical temporal variability of high latitude areas, with higher content of biogenic compounds (opal, OC and $CaCO_3$) linked to the phytoplankton bloom in spring–summer. However, on an annual basis local planktonic production is a secondary source for the downward OC, since most of the OC is laterally advected by the WSC.

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Marine sedimentary record of Meltwater Pulse 1a along the NW Barents Sea continental margin

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Keywords: Meltwater Pulse 1a, plumites, NW Barents Sea, Arctic.

The upper continental slope of the Storfjorden-Kveithola Trough Mouth Fans (NW Barents Sea) contains a several m-thick late Pleistocene sequence of plumites composed of laminated mud interbedded with sand/silt layers. Radiocarbon ages revealed that deposition occurred during about 130 years at a very high sedimentation rate of 3.4 cm a^{-1}, at about 7 km from the present shelf break. Palaeomagnetic and rock magnetic analyses confirm the existence of a prominent, short-living sedimentary event. The plumites appear laterally continuous and were correlated with the sedimentary sequences described west of Svalbard and neighbouring glacial depositional systems representing a major event at regional scale appointed to correspond to the deep-sea sedimentary record of Meltwater Pulse-1a. We also present new sedimentological and geochemical insights, and multi-beam data adding information on the palaeoenvironmental characteristics during MWP-1a and ice sheet decay in the NW Barents Sea.

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Paleomagnetic and rock magnetic study of sedimentary cores from the continental slope of the Ross Sea (Antarctica)

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Keywords: Paleomagnetism, Ross slope, Pennell-Iselin banks, Pleistocene.

We report paleomagnetic and rock magnetic data from the continental slope east of Pennell-Iselin banks in the Ross Sea. The research has been conducted in the framework of the Programma Nazionale di Ricerche in Antartide (PNRA) Rosslope II project (Past and present sedimentary dynamic in the Ross Sea: a multidisciplinary approach to study the continental slope), with the general aim to investigate the paleoclimate control on the present and past water masses circulation in this critical sector of the peri-Antarctic margin. Three cores (RS14-C1, RS14-C2, RS14-C3) were collected along a NNE-SSW transect which extends for ca. 100 km across the continental slope, and consist of hemipelagic fine-grained sediments with low IRD component. Low-field magnetic susceptibility (k), natural remanent magnetization (NRM) and anhysteretic remanent magnetization (ARM) were measured at 1 cm spacing on u-channel samples and stepwise demagnetized. Other rock magnetic parameters (ARM/k, median destructive field -MDF- and the gyromagnetic remanent ratio -ΔGRM/ΔNRM-) were obtained as potential proxies of paleoenvironmental variations. The results indicate that the sediments carry a well-defined characteristic remanent magnetization (ChRM) and therefore have a valuable potential to reconstruct dynamics and amplitude of the geomagnetic field variations at high southern latitudes during the late Pleistocene. Moreover, stratigraphic trends in some rock magnetic parameters in the more distal core (RS14-C1) appear to reflect paleoclimatic changes and are tentatively correlated to marine isotopic stages (MIS) in the MIS-1 to MIS-7 (ca. 250 ka) interval, thus enabling the definition of a chronological framework for the analyzed sequences.

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Palaeoenvironmental reconstruction on an expanded sedimentary sequence collected on the North-western margin of the Barents Sea (Arctic): preliminary results from CORIBAR core GeoB17603-3

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Keywords: Arctic, Kveithola, TMF, LGM.

The Kveithola depositional system is a small glacial trough, located South of the Svalbard Archipelago (North-western Barents Sea). The Kveithola trough has an E-W orientation and it is 90 km long, 15-20 km wide and 200-400 m deep (Rüther et al., 2012; Bjarnadóttir et al., 2013). During the last glaciation (MIS-2) it hosted ice streams, that contributed to build-up the Kveithola trough-mouth fan (TMF). TMFs are sedimentary depocenters derived primarily from debris-flow accumulation at the front of ice troughs on continental shelves (Vorren et al., 1989, 1998). The marine sedimentary record in TMFs provides the most direct proxies on ice-stream dynamics during glacial periods, the onset of the deglaciation and environmental/climatic variability during interglacials.

The TMF slope facing the Kveithola glacial trough has been investigated during the International Cruise CORIBAR on board the RV-Maria S. Marien (July-August 2013). Core GeoB17603-3 collected from the middle slope, contains a very expanded, continuous sedimentary sequence deposited after the Last Glacial Maximum (LGM), recording important information about the extent of the North-western terminus of the Barents Sea Ice Sheet (BSIS). We present some preliminary results on the sedimentological investigation of this core. Sediment analyses include determination of clay mineral assemblages, chemical composition of the sediments and textural characteristics. Clay minerals in this area are good indicators for the North Atlantic Current variation, associated to the climate change, whereas the chemical composition of the sediments clearly depicts the recommence of biological activity after LGM.

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Modeling the post-LGM deglaciation of the Scandinavian-Barents Sea Ice Sheet; a model intercomparison approach

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Keywords: Paleo Ice Sheet Modeling, LGM, Eurasian.

We aim at simulating the last deglaciation of the Scandinavian-Barents Sea (SBS) ice sheet. In particular, we focus on the Storfjorden and Bear Island ice streams, for which marine geological evidence suggests that they played an important role in the retreat of the ice sheet from the continental shelf edge during the last deglaciation, e.g., Rebesco et al. 2014, Lucchi et al. 2013, Ingólfsson and Landvik (2013). Two hybrid SIA/SSA numerical ice sheet models are employed, GRISLI, Ritz et al. 2001, and TARAH, Pollard and DeConto 2012. These models differ mainly in the complexity with which grounding line migration is treated.

The ice models are forced, from a spun-up initial condition, with spatially and temporally variable precipitation, surface air temperature, ocean temperature and ocean salinity fields. Climate forcing is interpolated by means of climate indexes between the Last Glacial Maximum (LGM) and the pre-Industrial (PI) climate. Regional climate indexes are constructed based on the non-accelerated deglaciation transient experiment carried out with CCSM3, Liu et al. 2009. Several indexes representative of the climate evolution over Siberia, Svalbard and Scandinavia are employed. The impact of such refined representation as opposed to the common use of the NGRIP $\delta18O$ index for transient experiments is analysed.

In this study, the ice-ocean interaction is crucial to reconstruct the deglaciation scenario in the area of the Storfjorden and Bear Island ice streams. To investigate the sensitivity of the ice shelf/stream retreat to ocean temperature, we allow for a temporal and a (vertical) spatial variation of basal melting under the ice shelves, using an implementation based on Martin et al. 2011 and simulated ocean temperature and salinity from the TraCE-21ka coupled climate simulation.

In this presentation, we will show work in progress, address open issues, and sketch future work. In particular, we invite the community to suggest possibilities for model-data comparison and integration.

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Southern Ocean modelling and implications related to climate change

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Keywords: Southern Ocean, Oceanography, Modelling, Climate Change.

Southern Ocean (SO) processes considerably affect climate and biogeochemical cycles (Rintoul 2011): in this context, ocean modelling plays a fundamental role in the detection and attribution of climate change in the region (Stocker et al., 2013). Here we review some relevant ocean modelling issues concerning the SO, with specific reference to the Antarctic Circumpolar Current and the Ross and Weddell seas, in a climate change perspective. Modelling aspects of the coupled ocean-ice-atmosphere system are also addressed. A special focus is on the intrinsic variability of the SO system (i.e., on the variability arising spontaneously due to nonlinearities without direct atmospheric forcing), whose identification is necessary to detect anthropogenic warming effects. Modelling the intrinsic low-frequency variability in the SO (which is known to occur on interannual to decadal time scales) presents conceptual and technical problems that are discussed in connection with both high-resolution eddy-resolving ocean general circulation models (Penduff et al., 2011; Sérazin et al., 2015) and idealized process studies (Sgubin et al., 2014; Pierini et al., 2016). Modelling studies in progress are also briefly described.

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Variability in chemical properties and in ventilation of the Ross Sea (Antarctica) waters and links to climate change.

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Keywords: Ross Sea, carbonate system, iron, AABW ventilation, climate change.

The Ross Sea (Antarctica) plays a significant role in the Southern Ocean carbon cycle by functioning as a major regional oceanic CO_2 sink and in the regional cycling of other essential bio elements, such as nitrogen, phosphorus and iron.

Sea ice dynamics control the surface waters (AASW) physical and chemical features and influence phytoplankton composition which has been shown to affect the relative concentrations of dissolved inorganic carbon and bioelements. Climate change feedbacks (AASW warming , reduction in sea ice extent and convective mixing) could decrease the supply of iron to surface waters during the growing season, although these impacts might be balanced out by increased inputs of iron- rich glacial and sea ice melt water (Smith et al., 2012). Substantial shifts in the chemistry of the oceans driven by anthropogenic CO_2 have occurred in recent times causing the phenomenon known as Ocean Acidification (OA), which is measurable by a decrease in pH and a shift in the carbonate equilibria. The Ross Sea is vulnerable to OA due to its relatively low total alkalinity (A_T) and because of increased CO_2 solubility in cold water (McNeil et al., 2010).

The Ross Sea contributes to the larger global ocean's overturning circulation, through the formation of dense High Salinity Shelf Water (HSSW) and the flow of Antarctic Bottom Water (AABW) off the shelf with profound effects on the heat budget of the Earth and impacts the regional and global climate.

AABW plays a significant role in the cooling and in the ventilation of the deep layers north of the western Ross Sea as it contains high oxygen concentration, consistent with the deepening of the surface water involved in the HSSW formation and in the export of inorganic carbon, particularly in the capture of the anthropogenic CO_2. Dropping formation rates, which lead to a reduced ventilation of Antarctic deep and bottom water masses, could have far reaching consequence like a declining uptake of CO_2 by the oceans, which would certainly amplify an ongoing global warming.

The chemical properties in the Ross Sea shelf area have been extensively studied by Italian Antarctic Research Program (PNRA) CLIMA, T-Rex and RoME Projects between 1998 and 2016, which has lead to an improvement in our understanding of their variability to ongoing climate perturbations.

The most relevant findings will be presented in this communication.

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Downslope and alongslope sedimentary processes on a high latitude continental margin: NW Barents Sea

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Keywords: glycogenic processes Barents Sea Trough Mouth Fans.

The development of high latitude continental margin has been mainly controlled by glacigenic processes during the glacial maxima. Superimposed to these, there are both downslope and alongslope sedimentary processes (turbidites and contourites). This study is aiming to study the relationships between the glacial sedimentary input and the water circulation in NW Barents Sea (Kveithola to Isfjorden Trough Mouth Fans). This portion of the Barents Sea has been the target of several surveys in the last decade: SVAIS (R/V Hesperides) in 2007, EGLACOM (R/V OGS Explora) in 2008, GLACIBAR (R/V Jan Mayen) in 2009, CORIBAR (R/V Maria S. Merian) in 2013, PREPARED (R/V G.O. Sars) in 2014 and the EDIPO and DEGLABAR cruises (R/V OGS Explora) in 2015. These cruises allowed the acquisition of a wealth of new multibeam data that are now jointly processed at OGS. During the most recent EDIPO/DEGLABAR cruise, from 20th September to 5th October 2015, we have been able to collect geophysical data, in particular Multibeam data, Sub-bottom profiles and Multichannel seismic profiles, as well as oceanographic data, including CTD and ADCP profiles. The EDIPO/DEGLABAR cruise focused the study of two areas in particular: the first one being the one W-SW of Isfjorden, on the Isfjorden TMF; the second one at SW of the Kveithola trough, on the INBIS channel. The INBIS channel originates from a series of tributary canyons, converging in a trunk-type channel, leading to a deep sea lobe system. The INBIS channel is inferred to have been produced by turbidity flows, flowing from tributary canyons incising the upper part of the continental slope between Bear Island TMF and Kveithola TMF. The INBIS channel is a very peculiar structure in the Barents Sea; channel systems are in fact rare on the Northern Norwegian margin and confined to the INBIS and Lofoten Basin channels. At W-SW of Isfjorden there is the evidence of alongslope sedimentary process, in the form of the Isfjorden drift. This structure is asymmetric, with a limited vertical relief. It is elongated alongslope, subparallel to the contour, due to the main current in that area, the north-flowing West Spitsbergen current. The analysis of the EDIPO/DEGLABAR data, integrated with all the other available information will allow to contribute to the comprehension of the relationships between the glacial sedimentary input and the water circulation in NW Barents Sea.

SAR ice thickness mapping in the Beaufort Sea using wave dispersion in pancake ice - a case study with intensive ground truth

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Keywords: remote sensing, frazil and pancake ice, SAR, Beaufort Sea.

Icefields composed of frazil and pancake ice play important roles in both polar regions in winter. During the early to midwinter period pancake ice is a major component of the Antarctic sea ice cover, while in the Arctic wide marginal ice zones are composed mainly of pancake/frazil ice. The concept of using the change in the wavelength of ocean waves on entering a frazil-pancake icefield, as measured by spectral analysis of SAR images, as a way of mapping the thickness of the ice, was originated several year ago by a seminal paper (Wadhams & Holt, 1991) and fully developed in the following years by two of the present authors (Wadhams et al., 2002, Wadhams et al., 2004). In our current work in the EU SPICES project (www.nersc.no/nb/project/spices) we plan to use the results of theory and observations so far in order to develop a processing scheme for routinely deriving ice thicknesses in frazil-pancake regions of the Arctic and Antarctic and hence assess their mass and heat balance. To do this we require more ground truth than had henceforth been available, the only direct comparison between satellite and shipborne work dating from more than ten years ago (Wadhams et al., 2004). In autumn 2015 (Sep 30 - Nov 10) the University of Alaska research ship "Sikuliaq" carried a team funded by the Office of Naval Research "Sea State Project" to study marginal ice zone processes in the Beaufort Sea, particularly wave-ice interaction processes. One such study involved a line of wave buoys laid out along a pre-declared line, which could thus be covered by simultaneous Cosmo-SkyMed images; in particular, the image dated from October 11 covered an area where frazil-pancake ice was the dominant ice type along the entire length of the survey line out to open water. The ground truth facilities deployed included: i) directional wave buoys placed in the water between pancakes; ii) "Swift" directional wave buoys placed outside of the ice edge; and iii) measurements of pancake ice thickness by recovery of cakes, and of frazil ice mass per unit area using a collector (a "frazilometer") giving a sample that is allowed to melt out. We report on the comparison between the wave fields measured by the buoys and the wave spectra derived from the SAR; and on the comparison between the ice thicknesses measured in situ and the thickness inferred from SAR wave number analysis with the application of a viscous theory.

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SESSION S16

Past climate change: from stratigraphic archives to interpretation

CONVENERS AND CHAIRPERSONS

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Marine calcifier shells as archives to understand the Earth system in the geological past

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Keywords: Biomineralization, end Permian, mass extinction, acidification.

Marine calcifier shells are high-resolution archives which record the physical and chemical properties of the seawater in which they live. Brachiopods and bivalves are known to record the primary seawater composition with no vital effect in their shell; hence, they can be considered excellent archives of proxies to understand the evolution of recent and ancient marine conditions.

There are a number of studies testing the response of extant marine calcifiers to changing environmental conditions, showing that several species are able to cope with these changes (e.g. decreased pH and reduced saturation level for calcium carbonates) on the short time scale. However, few studies evaluate the related change in shell microstructure and chemistry and very few take into account the long term evolutionary responses of the organisms in the natural environment.

Here, we use a new approach, which connects the microscale process of biomineralization to macroscale patterns in order to assess biotic changes and their potential causes during mass extinctions, considering both the extant organisms and the fossils shells . Based on microstructure changes, we show that the evolution of a more organic-rich shell is an important trait conferring advantages in undersaturated seawater conditions and it was important for survival during the end Permian mass extinction.

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Use of organic biomarkers for the Late Holocene reconstruction of fire and human presence in New Zealand

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Keywords: Organic biomarkers, paleoclimate, paleoenvironment.

The Polynesian colonization of New Zealand occurred quite recently in history (about 700-800 years BP) and resulted in abrupt and huge landscape modifications, as documented by sedimentary charcoal and pollen records. The native forest was not adapted to fire, thus burning for land clearance impacted dramatically on the ecosystem by modifying the composition of vegetation. Therefore, this location can be considered an extraordinary test site for the study of the very first human impacts on the environment.

Despite the incontrovertible evidence of some unprecedented fire events right after the arrival of the Māori, reconstructed through charcoal, its significance as a tracer for local and anthropogenic fire events has been questioned, stressing the need for new markers to confirm and complete the information about human presence and its effective impact. In the present work, novel organic molecular proxies are proposed for the reconstruction of fire events in association with anthropic activities. Namely, faecal sterols (FeSt), polycyclic aromatic hydrocarbons (PAHs) and monosaccharide anhydrides (MAs) were individuated as suitable molecular markers of human presence and fire activity, respectively. In particular, coprostanol accounts for about 60% of total sterol content in human faeces, being much less relevant in animal dejections. Together with its degradation product epi-coprostanol, it is well conserved in sedimentary archives and can be highly useful in paleoenvironmental reconstructions of human settlements. PAHs are produced in relevant amounts by combustion in conditions of oxygen depletion, and diagnostic ratios (DR) between specific molecules can be used for inferring fuel and sources. MAs are specific tracers of biomass burning, being generated only by the combustion of cellulose and hemicelluloses above 300° C.

The three classes of tracers were analyzed in a sediment core from Lake Kirkpatrick (570 m asl), and FeSt were analyzed also in a core from Lake Diamond (380 m asl). Both lakes are located in the Otago region, in New Zealand South Island.

The charcoal record for Lake Kirkpatrick (LK) and Lake Diamond (LD) shows major fire episodes around AD 1350, confirmed for LK by corresponding high levels of PAHs, ascribable to biomass burning (as further evidenced by DR), and MAs, both peaking at c. AD 1350. Moreover, the same trend is observed also in the fluxes of coprostanol and epi-coprostanol, whose sum results in two peaks at c. AD 1346 and 1351, respectively. For LD, a peak in FeSt is observed as well, slightly preceding the increase in fire activity starting around AD 1330. These findings confirm not only an important presence of humans in the area and the large use of fire at the time, but also the validity of selected tracers for complementing and refining the reconstructions enabled by charcoal analysis.

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Paleoclimatic changes at the Langhian-Serravallian transition (middle Miocene) through integrated stratigraphic data (Site DSDP 372, Western Mediterranean)

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Keywords: Western Mediterranean Sea, DSDP Site 372, Langhian-Serravallian transition, Calcareous nannofossils.

The Langhian-early Serravallian climatic evolution is marked by a transition between a warm period (Middle Miocene Climatic Optimum, 17-14.7 Ma), an 800 Kyrs long-term cooling phase (Middle Miocene Climatic Transition), and (13.8 Ma) the following "Icehouse" mode. This period is described by a long-lasting positive excursion of $d^{13}C$ ("Monterey Excursion"), showing a series of carbon isotope maxima (CM events; *Auctorum*) punctuated by cooling peaks in the oxygen isotopes (Mi events; *Auctorum*). Here we show the results of an integrated bio- (calcareous nannofossils) and chemostratigraphic ($d^{18}O$ and $d^{13}C$) analysis performed to reconstruct the paleoclimatic and paleoenvironmental evolution of the sea surface water in the DSDP Site 372 (Western Mediterranean; Abdul-Aziz et al., 2008). The studied interval (15.73-13.04 Ma) is defined by an older phase (spanning from the CM3 to CM4 events) showing low frequencies of the cold-water and eutrophic species *C. pelagicus* and high percentages of warm-water and oligotrophic genera *Calcidiscus*, *Sphenolithus* and *Umbilicosphaera* (Di Stefano et al., 2015 and ref. therein). The latter time interval (15.73-14.7 Ma), displaying low values of medium-size reticulofenestrids (high productivity and open marine conditions; Di Stefano et al., 2015 and ref. therein), reflects the presence of a warm, oligotrophic and quite closed environment, interrupted by the setting of the Mi2a event at ~14.8 Ma (increase of *C. pelagicus* and decrease of the warm-water groups). The intermediate interval (14.7-13.8 Ma), characterized by the onset of a climatic transition, is marked by the rise of *C. pelagicus* and the decrease of *Calcidiscus* and *Umbilicosphaera*. During the CM6 event (13.9-13.8 Ma), an abundance peak in *Discoaster* and *Sphenolithus*, accompanied by an increase of *Helicosphaera* and *Umbilicosphaera* and by a reduction of the medium-size reticulofenestrids and *C. pelagicus*, was recognized. The environmental reconstruction for the intermediate interval depicts a cooler and eutrophic setting in the lower and middle layers, and more restricted, warm and oligotrophic conditions in the younger layers. The cooling associated to the Mi3b (13.7 Ma) and Mi4 (13.4 Ma) events, triggered a drop in the warm-water and oligotrophic groups and an increase of *C. pelagicus* and medium- and large-size (cold-water affinity) reticulofenestrids, reflecting the beginning of the "Icehouse" mode.

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Changes in the coccolith carbonate export during the last deglaciation at ODP Site 1089 (Southern Ocean)

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Keywords: coccolithophores, last deglaciation, Southern Ocean.

Coccolithophore assemblages at TNO57-21 core drilled as part of ODP Site 1089 (40°57'S; 9°53'E, 4620 m water depth) were used to reconstruct paleoceanographic changes during the last 25 ky in the Subantarctic South Atlantic. This region has strong hydrographic gradients and ODP Site 1089 is optimally located in order to monitor how Subtropical Front, Subpolar Front and the Agulhas Current have evolved through time (Flores et al., 2003). The mean sedimentation rate is high, in the range of 15-20 cm/kyr, and recovered coccolith-bearing sediments provide a powerful tool to be used as a high-resolution indicator of the deep-sea carbonate export production. Models and sediment records indicate that the Southern Ocean abyss stored large amounts of atmospheric CO_2 during glacial periods that were rapidly released back to the atmosphere during glacial Terminations (Martínez- Botí et al., 2015). Here we present the productivity trend inferred from the *Florisphaera profunda* index and $CaCO_3$ concentrations per gram of sediment. These data clearly document a decrease in carbonate production throughout the last deglaciation. Moreover, we have calculated the *Calcidiscus leptoporus*-*Emiliania huxleyi* dissolution index (CEX'), which suggests a strong link between increasing coccolith dissolution and the evolution of the bottom water mass dynamics during Termination 1 (TI). Finally, data on species specific carbonate contribution are used to assess the role of each species as carbonate producer during the last 25kyr. The coccolith- based paleoceanographic reconstructions and carbonate dynamics reveal that during the last 25 ky the productivity was influenced by the mid-latitude westerlies, the study site was bathed by different bottom water masses, and was affected by a shoaling of the lysocline during T1 and the Holocene.

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Orbital control on the timing of oceanic anoxia in the Late Cretaceous

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Keywords: OAE2, Cenomanian-Turonian, Astrochronology, Carbon isotopes, Umbria-Marche.

The oceans at the time of the Cenomanian-Turonian transition were abruptly disturbed by a period of bottom-water anoxia. This led to the brief but widespread deposition of black organic-rich shales, such as the Livello Bonarelli in the Umbria-Marche Basin (Italy). Despite intense studies, the origin and exact timing of this event are still debated. In this study, we assess leading hypotheses about the inception of oceanic anoxia in the Late Cretaceous greenhouse world, by providing a 6-Myr-long astronomically-tuned timescale across the Cenomanian-Turonian boundary. We procure insights in the relationship between orbital forcing and the Late Cretaceous carbon cycle by deciphering the imprint of astronomical cycles on lithologic, geophysical, and stable isotope records, obtained from the Bottaccione, Contessa and Furlo sections in the Umbria-Marche Basin. The deposition of black shales and cherts, as well as the onset of oceanic anoxia, is related to maxima in the 405-kyr cycle of eccentricity-modulated precession. Correlation to radioisotopic ages from the Western Interior (USA) provides unprecedented age control for the studied Italian successions. The most likely tuned age for the Livello Bonarelli base is 94.17 ± 0.15 Ma (tuning #1); however a 405-kyr older age cannot be excluded (tuning #2) due to uncertainties in stratigraphic correlation, radioisotopic dating, and orbital configuration. Our preferred tuning #1 suggests that the exact timing of major carbon cycle perturbations during the Cretaceous may be linked to increased variability in seasonality (i.e. a 405-kyr eccentricity maximum) after the prolonged avoidance of seasonal extremes (i.e. a 2.4-Myr eccentricity minimum). Volcanism was probably the ultimate driver of oceanic anoxia, but the exact timing of carbon cycle perturbations in the Late Cretaceous was likely determined by orbital periodicities. This unites two leading hypotheses about the inception of oceanic anoxia in the Late Cretaceous greenhouse world.

Evolution of deep water exchange in the Atlantic Ocean during the latest Cretaceous – early Paleogene

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Keywords: Ocean circulation, Nd isotopes, Cretaceous, Paleogene, Atlantic Ocean.

In the greenhouse world of the Late Cretaceous, the different modes of deep- water formation and water mass exchange are poorly constrained, although, similar to today, deep ocean circulation likely played a major role in the distribution of heat over the planet. Maastrichtian bottom water εNd records from the North and South Atlantic display a wide range of values (-2 to -17) but are characterised by a similar trend towards less radiogenic values.

Two main hypotheses for this observation are brought forward: 1) Different mechanisms of deep water formation operated at the same time so that εNd signatures were strongly influenced by inputs from nearby continents. The parallel trends in Nd isotope compositions may thus reflect the vertical exchange with surface waters and a common trend of decreasing volcanism; 2) A common water mass dominated intermediate depths throughout the North and South Atlantic. Disparate Nd-isotope values observed near continental margins may reflect local overprinting of Nd- isotope signatures by continental inputs, boundary exchange processes, episodes of local volcanism, or the occurrence of deep water formation with a limited geographic range.

To tests these hypotheses, Nd isotope data have been generated for a range of locations in the North and South Atlantic. Improved time constraints through cyclostratigraphy and the generation of carbon isotope stratigraphies allow us to confidently determine the timing of changes in deep water mixing between the North and South Atlantic. Starting at 60 Ma, Nd- isotope values converged and an intensified mode of thermohaline circulation commenced.

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Unearthing climatic conditions and human impacts in the Eastern European Alps from the Ortles ice core during the last millennia

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Keywords: ice core, climate, human impacts, Estern Alps.

Ice cores contain a wide variety of past climatic and environmental information, preserving natural and anthropogenic signals for thousands of years. Oxygen and hydrogen stable isotopes have been widely used to reconstruct past atmospheric temperatures while anthropogenic pollutants such as heavy metals and black carbon provide insights in to the human impacts on the environment.

So far several ice cores were drilled in glaciers at mid and low latitudes, but the scarcity of Alpine ice cores covering a long time period suggests that the paleo-climatic potential of this mountain area, dramatically threatened by global warming, is still unexploited. The first ice cores drilled to bedrock in the Eastern Alps were retrieved during autumn 2011 on the "Alto dell'Ortles" glacier (3859 m, South Tyrol, Italy). This glacier is located close to densely populated and industrialized areas and can be used for reconstructing past and recent human impact.

The ^{210}Pb and ^{14}C dating of core #1 suggests that this should cover about 3000 years, making it one of the oldest records ever retrieved in the Alpine area. Thus O and H isotopic profiles describe the atmospheric warming and the low temperatures of the previous millennia.

The Ortles core #1 was processed at the University of Venice obtaining high-resolution discrete samples for stable isotope analysis. This core was also analyzed by mean of a continuous flow analyses (CFA) for conductivity, dust particles, trace elements and black carbon concentrations.

Samples were analyzed for water stable isotopes by using a Picarro L1102-*i* laser spectroscope and a Thermo-Fischer Delta Plus Advantage mass spectrometer. The obtained isotope record was compared to modern air temperatures, using data from an automatic weather station operating from 2011 to 2015 in proximity of the drilling site. In addition a reconstructed instrumental temperature record is available for the last 150 years.

The CFA offers a very high data resolution and allowed the simultaneous analyses of conductivity, dust concentration and size distribution (from 0.8 to 80 µm, "Abakus" Markus Klotz GmbH), trace elements with an Inductive Coupled Plasma Mass Spectrometer (ICP-MS, Agilent 7500) and refractory black carbon (rBC) with a Single Particle Soot Photometer (SP2, Droplet Measurement Technologies).

Anthropogenic trace element concentrations, total conductivity and the rBC concentration in the Ortles glacier may be related to the emissions from the Po Valley, one of the most polluted region of Europe, reaching the highest values during the second half of the 20th century. In addition, a significant increase of rBC was found in the Ortles ice core from the second half of the 1800s. This might be relevant because rBC is one of the most important aerosol species affecting the climate system, particularly the glaciers, by modifying the radiative energy balance.

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Atmospheric response to Quaternary climate changes as detected by palynological studies at Lake Ohrid (Balkans)

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Keywords: late Quaternary, Balkans, pollen, orbital and suborbital climate variability.

Lake Ohrid (Macedonia, Albania) is an exceptional continental site including at least the last 1.2 Ma history of changes in the Balkan peninsula, a key area of the Mediterranean. The productive collaboration among the different components of an international palynological team, including 12 researchers from 5 countries, provided effective implementation of the SCOPSO project (Scientific Collaboration on Past Speciation Conditions in Lake Ohrid) in the frame of ICDP (International Continental Scientific Drilling Program). In fact a long and continuous pollen record, for the last 500 ka, was produced in a relatively short period of time, at a millennial-scale resolution (~1.6 ka). This record permits the reconstruction of multiple non forested/forested phases corresponding to glacial/interglacial cycles which correlate, according to the established model-age, to marine isotope stages 13 to 1 (Sadori et al., 2016 and references therein). The achievement of this first step (Step 1), i.e. the topic of this contribution, as well as the ongoing collaboration aimed at the completion of the entire record by the end of 2016 (Step 2) and the implementation of high resolution studies in key intervals (Step 3), are truly relevant, the full pollen record permitting to trace by the analysis over multiples glacial/interglacial cycles: (i) the climate variability since 1.2 Ma when subtropical ecosystems disappeared by the central Mediterranean area, (ii) the history of taxa migration and extinctions under the effects of regional to global events, (iii) the role of refugia areas over the time. Moreover the ongoing climate reconstructions based on a multi-method approach (Modern Analogues Technique, Random Forests, and Weighted Averages regression) will provide an accurate quantitative reconstruction of the main climate parameters (e.g. mean annual Temperature and Precipitation). The palynological evidence, supported by a large number of studies documenting the peculiar geological and morphological context of Lake Orhid, permits to trace successive paleoclimatic and paleoenvironmental changes in response to orbital and sub-orbital forcings. Such an integrate approach strongly contributes to clarify the atmospheric vs oceanic response to the main global climate changes and then to propose a more comprehensive paleoenvironmental history for Lake Ohrid which is an indispensable element of knowledge to predict its future.

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Mid-Cretaceous climatic fluctuations traced by calcareous nannofossils

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Keywords: mid-Cretaceous, calcareous nannofossils, paleotemperature.

Several regional to global episodes, known as Oceanic Anoxic Events (OAE)s occurred over the Aptian – early Turonian time interval and were characterized by excess CO_2, intense volcanism, perturbed climate and altered oceanic chemistry. In order to either understand the dynamics leading to these "extreme" conditions and the ocean-atmosphere system recovery after the OAE, it is important to focus on a longer-term record thus to include the sequence of intervals of perturbation and the phases of stable conditions. For this purpose, calcareous nannoplankton is a useful tool, since it is extremely sensitive to changes in surface waters parameters like temperature and nutrient content and interacts with the C cycle through biological processes and production of calcareous oozes. We gathered new quantitative nannofossil data for the Tethys Ocean (Umbria Marche Basin, Italy) to derive climatic fluctuations and changes in ocean fertility during the late Albian – early Turonian. The new dataset was integrated with the nannofossil data collected for the Aptian – early Albian time interval to provide a compilation of temperature and surface water nutrient variations on the long-term through the Aptian – early Turonian interval in the western Tethys. The nannofossil Temperature Index (TI) outlines warm conditions for OAE 1a, followed by a cooling trend culminating soon after the *N. truittii* acme interval. Progressively increasing temperature (T) characterized instead the latest phases of the Aptian and warmer conditions were reached in the Albian – Cenomanian, although interrupted by relatively cooler phases, as for example in correspondence of the MCE. The highest paleo-T were reached across OAE 2. Surface water fertility (F) resulted instead to be relatively high during most of the early-middle Aptian, exception made for the *N. truittii* acme interval when a significant decrease occurred. The latest Aptian – early Albian interval was marked by intermediate trophism in surface waters, with intervals of higher F during black shales deposition. During the interval comprised between the OAE 1b and the OAE 1d, F was relatively high while it decreased in the Cenomanian. A distinct F pulse was detected prior to OAE 2. We correlated the TI with available paleo-T proxies: a good correlation exists with the $ð^{18}O$ records through the Aptian - upper Albian but it is not possible to provide a comparison for the lower-middle Albian since there are no $ð^{18}O$ data available. During the Cenomanian, the trends of the two paleo-T records are instead the opposite, with the TI shifted towards cooler T and displaying oscillations not evidenced by the $ð^{18}O$. Further paleo-T reconstructions are available across the upper Aptian - lower Albian from TEX_{86} data from the proto-North Atlantic Ocean and show very good correspondence with the TI. We therefore calibrated the TI (which does not provide absolute T values) on the basis of TEX_{86} paleo-T and estimated the extent of T-variations.

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Preliminary calcareous nannofossil results from IODP Site U1410 (NW Atlantic) across the Early Eocene Climatic Optimum

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Keywords: calcareous nannoplankton, early Eocene, Northwest Atlantic, biostratigraphy, climate variability.

The Early Eocene Climatic Optimum (EECO), 52-50 million years ago, is an intriguing interval of the Cenozoic characterized by a long-lived maximum in global temperatures and high *p*CO2 values (Zachos et al., 2001). At present, the potential relationships among biotic evolution, carbon cycle and climate during the early Eocene are poorly documented because available high resolution, continuous and expanded stratigraphic records are very few. Here, we present quantitative analyses of calcareous nannofossil assemblages from a deep-sea succession (paleo water depth 2950 m) recovered at the mid-latitude IODP Site U1410 (Exp. 342; Latitude: 41°19.6987′N; Longitude: 49°10.1995′W, Norris et al., 2012) in the Southeast Newfoundland Ridge (NW Atlantic). Calcareous nannoplankton are a major component of marine primary productivity and play a crucial role in the carbon bio-geo-cycles. They are in fact a high sensitive group able to capture changes in the paleoenviromental conditions. Previous studies on early Eocene calcareous nannofossil assemblages have pointed out that this group was deeply affected during and after the EECO. The Paleocene Prinsiaceae family went extinct and the modern-like coccolith belonging to Noelaerhabdaceae family (i.e, *Reticulofenestra/Dictyococcites* group) first entered in the record. At IODP Site U1410, preliminary data on the early Eocene sequence indicate that a quite expanded succession spanning the nannofossil biozones NP12/NP13 or CNE4/CNE5 is documented. During the EECO, the background *Toweius*-dominated assemblages was substituted by the *Reticulofenestra/Dictyococcites*-dominated assemblages This evolutionary turn-over was associated with a *Discoaster* Acme, during which *D. kuepperi* flourished. The EECO was characterized by an oligotypic assemblage dominated by few oligotrophic taxa (e.g., discoasters, sphenoliths, *Zygrhablithus*), which eventually gave way to a profound and irreversible readjustment of calcareous nannofossil assemblages.

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Following the giant: a Late Permian ichnology tale from the Bletterbach Gorge (Redagno, Italy)

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Keywords: Arenaria di Val Gardena, trackways, trackmakers, substrate, Late Permian.

Countless magnificent tracks of different tetrapod trackmakers, preserved as convex hyporeliefs on a single slab pulled out at the Bletterbach Gorge from Upper Permian Arenaria di Val Gardena Fm., were studied in order to unveil trampling history. Trackmakers crossed the surface in different directions, and, as result, many footprints interfere each other, so that a detailed narrative of the events is recorded. The dark-red siltstone slab is about 2.5 m long, a maximum of 1 m wide, and about 3 cm thick. Ten trackways and some isolated footprints, on the whole referred to as *Pachypes dolomiticus*, *Ganasauripus ladinus*, *Janusichnus bifrons* and *Chelichnus tazelwürmi*, were identified, plus some probable invertebrate traces. Tracks range in dimensions from about 2 cm (i.e. *Chelichnus tazelwürmi*) to about 20 cm and were left by trackmakers of very different order of weight. Nine of the trackways and some large *Pachypes dolomiticus* isolated tracks reciprocally interfere with one or more trackways by overprinting and/or intersections, allowing tracing back a relative timing of surface crossings. Track preservational features were directly observed and qualitatively evaluated in the light of trackmaker dimensions, indicating for several trackways a quite plastic substrate. High-resolution Digital Photogrammetry was then applied to accurately quantify the tracks relief (i.e. depth of impression), resulting very little variable. Interpreting data contextually, the very similar substrate conditions (i.e., sediment cohesion and sediment reaction to the applied load) inferred for some trackways left by so different trackmakers suggest days or, less likely, weeks, of surface compliance. As a matter of facts, Late Permian time have to be consumed up to the sediments reached for the producer of *Pachypes dolomiticus* 'the same substrate condition' (i.e., sediment cohesion and sediment reaction to the applied load) to those existed, for example, when the producer of *C. tazelwürmi* crossed the same surface. Thus, the giant pareiasaurian turns out to be the reading key to the problem. The analysis of this event timeline has also suggested that caution should be exercised in analyzing tracks interferences, especially when multiple and different lines of evidence are lacking. As a consequence, the timeline of events may be masked and misinterpreted with obvious repercussions on general reconstructions. The need to deeply understand, case-by-case, the close interdependence between the momentary substrate conditions, trackmaker morphology, dimensions and behaviour, and the 3D track morphology is highlighted. This understanding is pivotal in tetrapod ichnology, as it allows the direct investigation of the processes leading to track formation. While time-intensive, it could be a useful investigative tool preliminary to traditional ichnological analysis, for which the control on the mode of preservation of the footprints is crucial.

Using the CT-scan as a tool to recover information from traded fossils: an example on a plesiosaur skull

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Keywords: Paleobiology, Elasmosauridae, CT scanning, vertebrate palaeontology.

The illegal trade of fossils has always been a threat to the scientific relevance of specimens eventually recovered from the black market. In 2008, a huge private collection including hundreds of fossils was seized by the authorities of the Cultural Heritage in the town of Serrapetrona (Macerata, Marche, Italy). Most of the specimens were devoid of any information about the provenance or taxonomic attribution, and since their recovery, the joint efforts of the Serrapetrona Municipality, the Cultural Heritage authorities, and the Department of Earth Sciences of the 'Sapienza' University of Rome were dedicated to return this patrimony to the public. Many specimens are clearly made-up to hide the reconstructed portions, with the risk to lose the information about the truly preserved elements. Here we present a possible tool to recover important data from traded fossils, that could still be useful to improve our knowledge about the life in the past.

Among the material currently housed in the Museum of Serrapetrona, we chose a plesiosaur-like skull(MSP 272) as a case study. The specimen was covered with a homogeneous varnish, so that its authenticity was very doubtful. Our main goal was to investigate the validity of the fossil, but due to the evident fragility of the skull elements, in order to avoid any damage by removing the varnish, we decided to perform a computed tomography (CT-scan). This method is commonly used in archaeological investigations, and is spreading in paleontology, especially to unveil possible frauds.

This technique provides an accurate model of both the external and internal structures of the object according to the density of the material of which it is composed. This process allows to discriminate and virtually separate the fossilized portion from the reconstructed one, avoiding an invasive procedure that could damage the specimen. The CT imaging was carried out with a slice thickness of 0.8 mm, and the captured data were processed using OsiriX 3.4.

Our analysis revealed that the posterior portion of the temporal fenestrae, most of the mandibles, and some teeth were reconstructed, while the rostral, orbital and anterior temporal regions are truly preserved and only partially remodelled. The presence of a single upper temporal fenestra places our specimen among euryapsids; other characters such as the external position of the anterior nares related to the posterior ones, and the presence of a posteromedian ridge of the supraoccipital allowed us to recognize the fossil as a plesiosaur, and in particular as belonging to Plesiosauroidea. Moreover, considering that the frontal contributes to the edge of the temporal fenestra, and that the postfrontal is excluded from the orbit, we were able to assign the specimen to the family Elasmosauridae.

Further comparative studies of the bones together with the analysis of the sediment might help in retrieving more information, and potentially go deeper into the taxonomic attribution, and the provenance of the specimen. Once the preserved elements are identified using the CT-scan, the material can be finally re-prepared for a proper musealization where fossilized and reconstructed parts are visually differentiated.

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Evolution, decline in abundance and change in coiling direction of planktic foraminiferal *Morozovella* during the Early Eocene Climatic Optimum

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Keywords: Planktic foraminifera, Morozovella, Early Eocene Climatic Optimum, evolution, coiling direction.

Planktic foraminiferal assemblages display distinct evolutionary trends that can often be correlated to climate variability (e.g. Fraass et al., 2015). A major diversification occurred within this group during the early Eocene although the relationship between climate variability and evolution remains insufficiently known. The symbiont-bearing surface-dweller planktic foraminiferal genus *Morozovella* is of particular interest because of its dominance in tropical-subtropical assemblages of the early Paleogene oceans. This genus shows a marked and permanent decline in abundance and change in taxonomic diversity at the beginning of the Early Eocene Climatic Optimum (EECO; ~49-53 Ma), the interval when Earth surface temperatures reached their Cenozoic maximum. We record this decline, previously documented for the northwest Pacific (DSDP site 577), northwest Atlantic (ODP Site 1051) and western Tethys (Possagno section, northern Italy) (Luciani et al., 2016) also in SE Atlantic (ODP Site 1263). The investigation of quantitative abundance of *Morozovella* species shows that the general decrease in abundances of the genus appears unrelated to the disappearance of a single dominant species and the exact cause for the abundance decline in *Morozovella* remains yet elusive. However, a change in coiling direction involving the whole *Morozovella* population unexpectedly occurred during the EECO. Morozovellids display indeed a dominant dextral preference during the interval preceding the EECO but all species show a gradual change to dominant sinistral morphotypes starting slightly above the carbon-isotope excursion known as J event, recently considered as the start of the EECO (Luciani et al., 2016). This switch from dextral to sinistral forms became permanent after the K/X event up to the middle Eocene. In recent oceans the sinistral and dextral forms dominate respectively in colder and warmer waters even though the two most studied left- and right-coiled forms, previously believed as ecophenotypes, have now been recognized as genetic traits of two different species (*Neogloboquadrina pachiderma* and *N. incompta* respectively, e.g., Darling et al., 2006). The cause of coiling direction change remains an intriguing problem especially for extinct species. Geochemical data will provide proof of possible sea surface temperature variability at the coiling change recorded in Eocene morozovellids. Our record stimulates further investigation to comprehend the true relationship between evolutionary trend and climate variability.

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Was the permanent decline of Morozovella at the start of the Early Eocene Climatic Optimum caused by lost of photo-symbionts?

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Keywords: Early Eocene Climatic Optimum, Planktic foraminifera, Morozovella, photosymbionts, bleaching.

The symbiotic relationship with algae is a critical strategy adopted by many modern species and by shallow-dwelling planktic foraminifera during the early Paleogene. The endosymbionts play an important role in foraminiferal calcification, longevity and growth, allowing the host to succeed in oligotrophic environments (e.g., Hemleben et al., 1989). We have indirect evidence on the presence or loss of photosymbionts (bleaching) because symbionts modify the chemistry of the microenvironment where a foraminifer calcifies. A characteristic geochemical signature is thus recorded in the isotope ratios of the fossil shells even though symbiont-algae are not preserved (e.g., Elderfield et al., 2002). However, the exact role of photosymbionts in extinct taxa is not fully understood. Data from fossil record are crucial because allows us to detect how calcifiers responded to past global warming events that have similarities with the ongoing increasing ocean temperature and acidification. A temporary bleaching related to intense global warming involved large *Acarinina* and *Morozovelloides* at the Middle Eocene Climatic Optimum, centered at ~40Ma (Edgar et al., 2012). The end of the symbiont relationship is involved in the extinction of the abovementioned genera at the late middle Eocene (Wade et al., 2008). The symbiont-bearing genus *Morozovella,* morphologically and ecologically comparable with *Morozovelloides*, was one important calcifier of the early Paleogene oceans. A marked and permanent decline in abundance of this genus is recorded at low-latitude sites at the onset (~53Ma) of the Early Eocene Climatic Optimum (EECO; Luciani et al., 2016), the interval when Earth surface temperatures reached their Cenozoic maximum. The record from the northwest Atlantic ODP Site 1051 offers the opportunity to test a possible bleaching as a potential cause of the permanent morozovellid decline. We demonstrate through the established relationship between test size and $\delta^{13}C$ that a reduction of algal-symbiont relationships involved the genus *Morozovella* at the start of the EECO. The recorded bleaching was however a transient effect and it cannot be therefore considered as the possible cause of the permanent morozovellid decline that remains yet elusive.

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Tempo and mode of calcareous nannoplankton evolution: the rise of highly-calcified nannoliths in the Tithonian

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Keywords: calcareous phytoplankton, evolution, micrite-forming nannoliths, latest Jurassic.

The history of calcareous nannoplankton shows a general increase in species richness through the Mesozoic. Fertility and chemistry of the oceans, climate and $p\mathrm{CO_2}$ seem instrumental for nannoplankton abundance, diversification and adaptation, but high-resolution chronology of paleobiological and geological events is crucial for the understanding of evolutionary processes relative to ecosystem perturbations.

Natural variations in atmospheric CO_2 are essentially triggered by igneous activity that also controls the ocean chemistry and nutrient cycling. In particular, the seawater Mg/Ca ratio is related to seafloor spreading and hydrothermal processes. High production of ocean crust results in high Ca^{2+} concentrations, low Mg^{2+} concentrations and low Mg/Ca ratio, and vice versa.

During the latest Jurassic calcareous nannoplankton experienced a series of extinctions followed by originations within coccolithophore families resulting in a major turnover that impacted the oceans at global scale for some 20 millions years. In particular, the appearance and development of three nannolith groups, namely Conusphaera, Polycostella and Nannoconus strongly affected biogenic sedimentation in the oceans with consequent major increase in biogenic calcite production. Specifically, during the late Tithonian, the heavily calcified and large nannoconids produced massive pelagic carbonates and are often regarded as the first effective carbonate-producers in the Mesozoic oceans.

The Tithonian origination of coccoliths and nannoliths suggests ideal paleoecological conditions for calcareous nannoplankton, presumably thriving in stable, relatively oligotrophic and cool oceans under low $p\mathrm{CO_2}$. Nannoliths became dominant in the late Tithonian perhaps under cooler climatic conditions that affected the oceanic structure and circulation, possibly establishing a thermocline in the lower photic zone.

Recent high-resolution bio-magneto-stratigraphy revealed the sequence of originations and their timining relative to the major tectonic-igneous event associated to the construction of the Shatsky Rise in the Pacific. Tempo and mode of nannoplankton innovation in the latest Jurassic is used to derive causal or casual relationships between the geosphere and the biosphere. Stable environmental conditions seem to have favored K-selected nannoplankton whose evolution might have further benefitted of magmas especially rich in biochemically important elements from the mantle.

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Were ocean acidification and trace metal loading detrimental to calcareous nannoplankton calcification during the latest Cenomanian Oceanic Anoxic Event 2?

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Keywords: OAE2, nannofossil, CO2, trace metal.

The Cretaceous was characterized by greenhouse climate conditions and profound environmental perturbations including Oceanic Anoxic Events (OAEs), episodes of widespread organic matter burial in oxygen-depleted oceans.

In this study we focus on the latest Cenomanian OAE 2 (~ 94 Ma) that is thought to be related to the emplacement of the Caribbean Plateau which probably introduced in the atmosphere a large amount of CO_2 with consequent impact on biota, climate and ocean chemistry. The perturbation of the carbon cycle is reflected by the carbon isotopic record, that evidences a positive shift at the OAE 2 onset and subsequent C isotopic peaks.

Morphometric analyses were performed on coccoliths of *Biscutum constans*, *Discorhabdus rotatorius*, *Watznaueria barnesiae* and *Zeugrhabdotus erectus* from five sections spanning the Cenomanian-Turonian boundary interval including OAE 2 (~ 94 Ma). The study provided evidence for size fluctuations and reduction of *B. constans Z. erectus* and *D. rotatorius* during OAE 2, followed by a partial recovery at the end of the event. *B. constans* appears to be the most sensitive species, with similar and coeval size trends in all the analyzed sections. Conversely, specimens of the most common taxon *W. barnesiae* display rather constant sizes through the event.

The comparison of our morphometric data with those available for the early Aptian OAE 1a and latest Albian OAE 1d, indicates that *B. constans* repeatedly underwent size reduction and temporary dwarfism possibly implying that the same paleoenvironmental factors controlled calcification of this species during subsequent OAEs: the amplitude of *B. constans* coccolith reduction is different for OAE 1a and OAE 2, but similar minimum values were measured evoking the existence of a critical minimum size. Paleoceanographic reconstructions suggest that ocean chemistry related to the amount of CO_2 and (toxic) metal concentrations played a central role in coccolith secretion with a repetitive reduction in size during OAEs, while temperature and nutrient availability do not seem to have been crucial for coccolith calcification. Ultimately, during OAEs calcareous nannoplankton inability to properly calcify might have favored other phytoplankton than coccolithophores facilitating a transient spread of more competitive functional groups.

Towards a ~1.5 Ma-long record of the central Mediterranean climatic and explosive volcanism history: first results from a pilot drilling in the Fucino Basin, central Italy

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Keywords: Central Mediterranean, lacustrine sucession, Quaternary.

Much of our knowledge and understanding of the spatiotemporal variability and mechanisms underlying Quaternary climatic changes rely on regionally representative, high-sensitivity and chronologically well constrained proxy records. Quaternary lacustrine successions from Central Apennine tectonic basins in central Italy, have been shown to fulfill these requirements, giving fresh insights on the most cogent palaeoclimatic issues which are under current debate (Giaccio et al., 2015a; Regattieri et al., 2015; 2016). Among these tectonic depressions, the Fucino Basin is the largest and probably the only one that hosts a continuous and thick (~900 m) succession spanning between ~1.5 Ma and the present. Furthermore, the basin is in a favourable position with respect to the prevailing westerlies and in a good range of distance from the main volcanic centres (100 to 150 km), producing a quite complete record of distal tephras which can be successfully dated either directly, by mean of the $^{40}Ar/^{39}Ar$ method, or indirectly, by tephrostatigraphic correlations (Giaccio et al., 2015b).

With the aim of exploring its potential and suitability for a deep drilling project, in June 2015 an 82 m-long sedimentary succession was retrieved from the Fucino basin. The direct ($^{40}Ar/^{39}Ar$) and indirect (geochemical fingerprinting) dating of 22 stratigraphically ordered tephra provided precise constraints on the chronology of the investigated Fucino succession over the last ~190 kyr. Multi-proxy geochemical analyses (XRF scanning, total organic/ inorganic carbon, nitrogen and sulphur, oxygen isotopes) revealed noticeable variations, which have been interpreted as palaeohydrological and palaeoenvironmental expressions related to both glacial-interglacial cycles and sub-orbital climatic changes over marine isotope stage 6 to the present day. In light of the preliminary results, the Fucino sedimentary succession is likely to provide a long, continuous, sensitive, and independently dated palaeoclimatic archive of the central Mediterranean area.

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The large lituolid Navarella Ciry & Rat 1951: an upper Paleocene Lazarus occurrence?

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Keywords: Lazarus taxon, Agglutinated Foraminifera, Paleocene, Scaglia Rossa, Belluno Basin.

Navarella is an upper Cretaceous large lituolid, attaining a maximum length of 5 mm, with a first streptospirally enrolled test, later uncoiled and with an aperture varying during the ontogenesis from slit-like to cribrate. The genus was originally described by Ciry & Rat (1951) from the Maastrichtian flysch of the Spanish Pyrenees, then reported from Campanian-Maastrichtian rocks of Suisse Alps, Bavaria, Austria, northeastern Italy, France and Serbia (e.g., Maync, 1954; Sampò, 1972; Radoičić et al., 2010).

Recently, several large *Navarella*-like lituolids were discovered in Thanetian hemipelagites of the Belluno Basin (Giusberti et al., 2016; Plate 4, figs. 14, 20). They are common in the >500 µm fraction of the residues up to the uppermost Thanetian and abruptly disappear at the Paleocene-Eocene boundary, in coincidence with the exit of Paleocene cosmopolitan extinction taxa (Benthic Foraminiferal Extinction Event; Giusberti et al., 2016).

In order to document the internal chamber arrangement and the agglutinated wall microstructure of the Paleocene lituolids and to compare them with *Navarella*'s individuals recovered in Maastrichtian strata of the study area, the specimens were sectioned and analysed through a scanning electron microscope (SEM) equipped with an energy-dispersive X-ray spectrometer (EDX). Our results confirm the attribution of the Paleocene specimens to *Navarella*, thus permitting to expand the stratigraphic distribution of this poorly known deep-water lituolid.

Despite intensive researches, we did not find any trace of *Navarella* in Danian-Selandian strata, implying a >7 Myr gap in the stratigraphic range of this peculiar agglutinated foraminifer. Based on available data, we infer that *Navarella* reappeared as "Lazarus" genus in the Thanetian having survived the Cretaceous-Paleocene mass extinction, but it was eventually driven to extinction during the environmental perturbations associated to the Paleocene-Eocene Thermal Maximum (Giusberti et al., 2016).

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Cenozoic Small Mammals of Mediterranean Islands: Facts and Problems

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Keywords: Insularity, small mammals, Mediterranean Islands.

Insular faunas have attracted the interest of naturalists for their peculiarities since Darwin and Wallace time. For the Mediterranean islands are mostly the large mammals (proboscideans and artiodactyls) with their strong decrease in size, that have polarized the attention, but also the small terrestrial mammals (Eulipotyphla, Lagomorpha, Rodentia) normally characterized by an increase in size, have been subject of many studies. Insular faunas are characterized by endemism (but what is endemic? Obvious for extant and Pleistocene assemblages more less for Eocene ones), modification of the size of mammals and low biodiversity. On the basis of these observations the famous Miocene faunas of Samos, Chios, and other less known faunal assemblages from other Greek islands are clearly "normal" continental assemblages. On the other hand the faunal assemblages of Gargano, Scontrone and Baccinello, currently areas that are part of the Italian peninsula, and Murchas now part of the Iberian Peninsula, are typical insular faunas. The hard evidence (the facts) about the small fossil mammals of the Mediterranean islands consists in the knowledge of fossiliferous sites of Paleogene (Majorca), Neogene (Majorca, Menorca, Ibiza, Sardinia, Tuscany, Scontrone/Gargano) and Pleistocene (all the large Mediterranean islands and several small ones) that yielded remains of these orders. The numbers of fossil species of insectivores, rodents and lagomorphs described so far for the islands in question (including those classified as aff.) are approximately as follows: Eulipotyphla 30 species (1 Paleogene, 17 Neogene and 12 Pleistocene), Lagomorpha 13 species (9 Neogene and 4 Pleistocene), and Rodentia 94 species (12 Paleogene, 55 Neogene – most of them from Gargano – and 27 Pleistocene). For many of these species are known with reliable certainty margins the routes of dispersion and the time of colonization of the island areas, the ancestral continental species from which most likely descend, and the time of extinction. However many problems about the ways of dispersion, the evolution of various lineages, the extinction of many taxa remain open (origin of the thryonomyid of Majorca or of the ctenoctalylids of Sardinia, time of colonization of some murids of Gargano, contemporaneous presence of a murid and his putative ancestor in Sardinia, origin of the giant glirid of Sicily and Malta, extinction of a large murid of Crete hardly explained by the competition from a small species of the same family who arrived on the island, etc.).

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Lopingian (late Permian) terrestrial fossil record strongly biased by long term climatic conditions and sea-level changes

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Keywords: Permian, sea level changes, fossils preservation.

The Permian was characterised by long term climatic conditions that influenced the composition and dynamics of terrestrial ecosystems. The Lopingian was characterized by a general aridisation process and significant sea-level changes. The fossil record is consequently strongly affected by environmental and taphonomic factors. The worldwide famous Bletterbach Gorge sedimentary succession (South Tyrol, Italy) offers a unique opportunity to reconstruct the evolution of the ecosystem through the Lopingian-Anisian time intervals. The Lopingian deposits record a paleoequatorial to low-latitude terrestrial ecosystem (about 5-10° N) where plant remains with traces of plant-animal interactions and tetrapod footprints are exceptionally preserved. The applied multidisciplinary approach, based on sedimentology, palaeobotany and palaeoichnology allowed disentangling preservation bias from true biological signal. Two different plant assemblages were detected within the succession based on the fossil content and preservation. Flora A, composed of hygrophytic elements with large leaf/shoot fragments, occurs close to a sea-level highstand and is thus interpreted as a (par)autochthonous assemblage of an intrazonal riparian vegetation. Flora B is dominated by xerophytic elements documented by smaller fragments, corresponds to an allochthonous assemblage of an azonal vegetation preserved in floodplain fines of a progradational fluvial plain associated with a sea-level lowstand. Vertebrate tracks distribution mirrors that of plant-bearing horizons and their abundance and diversity strongly increases in correspondence with marine transgressions. This abundance can be explained by a more diverse fauna related to a complex food-web and more humid conditions or, alternatively, to more favourable taphonomic conditions. The most diversified fauna, recorded during the early phases of the regressive phase, can be well explained by the rapid burial of tracks due to the increasing energy. This study provides an explanation for the distribution and preservation of plant and animal fossils in the Bletterbach section and shows how the continental fossil record can be deeply affected by sea-level changes.

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Links between life and climate changes in the history of the Earth: synergy between planetary geology and terrestrial geology

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Keywords: Earth, planets, water, life, cyanobacteria, Hadean, Archean, climate change, carbonates, isotopes

The Earth, as well as the other terrestrial planets, was dry immediately after its accretion and had a CO_2-rich atmosphere (Shaw 2008) but then water accumulated on the planet and made the difference for life and plate tectonics; the Xe isotopic signature suggests the presence of the first water in the atmosphere of the Earth already in Pre-Archean ages, between 50 and 120 Ma after the formation of the Solar System (Albarede 2009; Marty 2012), but the D/H ratio is important to understand its origin (Altwegg et al. 2015). The first environmental indicators related to the presence of life forms (microfossils morphologically similar to cyanobacteria) were already found in the Archean (3.42-3.26 Ga ago) cherty metasediments of the basaltic Hooggenoeg and Kromberg Formations on Earth (Walsh 1992). Although these findings were questioned as possible self-organizing structures (SOS) as for the case of stromatolites (Grotzinger & Rothman 1996), there is no widespread report of SOS in Martian meteorites or lunar samples. Cyanobacteria are particularly important for their long evolutionary history (~3.5 Ga) and for their vital activity related to climate changes (Paerl & Otten 2013). The Great Oxygenation Event (GOE), when cyanobacteria produced large amounts of oxygen that killed most of the anaerobic bacteria on Earth (Jackson 2015), was thought as the oldest (~2.45 Ga ago) known (Holland 2006). The oxygen emitted in the atmosphere reacted with existing greenhouse gases (e.g. methane), also associated with biological sequestration of carbon dioxide, and possibly triggered the Huronian glaciation known as the longest (~2.4-2.1 Ga ago) period of cold climate during the Proterozoic (Hilburn et al., 2005). However, an older glaciation was already found in the Kaapvaal craton and occurred in the Archean, ~2.9 Ga ago (Young et al., 1998). There is no reason to exclude that even an older one may have existed before. The presence of cyanobacteria already in 3.42 Ga old Archean rocks indicates that some time must have passed since their first evolution and may indicate that their primordial embryos might even be found in older Archean and pre-Archean layers characterized by the presence of carbonates. Carbonates (Brasier et al. 2006) in Archean layers and indirect trace of life activity from Pre-Archean carbon isotopes (Bell et al. 2015) provide good stratigraphic references from which further and new search should start. Planetary geology is particularly important to understand the origin of water in the history of Earth and of the other terrestrial planets, the end of the Hadean (pre-Archean) eon, and how the astronomical factors (catastrophic events like asteroidal or cometary impacts associated with mass extinctions) shaped our planet and influenced its climate in the past.

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The Middle Pleistocene Transition in the NW Pacific (ODP site 1209): paleoceoanography reconstruction through a multidisciplinary approach

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Keywords: Middle Pleistocene Transition, Calcareous nannofossil, NW Pacific.

During the Quaternary the climate shows two dominant states: glacial and interglacial. Evidence for multiple glacial-interglacial cycles is preserved in ocean-sediments, ice cores and terrestrial archives (e.g. Shackleton, 1969; Elderfield et al., 2012). During the Middle Pleistocene Transition (MPT; 1.25-0.65Myr; Raymo et al., 2004; Clark et al., 2006), the climate underwent a switch from a 41kyr periodicity to a quasi-periodic 100kyr cycle. The MPT represented an important phase of climate re-organization however the mechanisms of this revolution is still unclear.

The ODP site1209 cored in the NW Pacific Ocean offers a good opportunity to investigate the climate and oceanographic evolution of the region by mean of a high-resolution and well preserved sedimentary record. We studied the calcareous nannofossil content at the site during the last 1.3Myr in 212 samples. Among these, 48 samples are older than the MPT, 82 samples belong to the MPT and 82 samples are younger than the MPT. Through a statistical approach, we test if the clusterization of sample could be dependent on the age of each sample, the climate phases in which the sample is (glacial or interglacial stage), and/or the MPT interval. Alternative models were formulated and checked using a Permutational Multivariate Analysis of Variance: H_1 assumed that sample distribution depends on time, H_2 accounts for climate conditions, whereas H_3 assumes the effect of MPT. Model comparison shows that H_3 is the most representative explaining the 28% of total variance in sample assemblage. Moreover, the Canonical Analysis (CA) performed on the nannofossil data reveals that the first component regulating the samples distribution could be dependent on the climate system while a second one could represent an intrinsic properties of the assemblages. Therefore, only a multidisciplinary approach could draw the effects of MPT on the nannofossil assemblages. The integration of biotic data with information about pCO2, eolian flux, carbonate content of sediments could clarify the progressive oceanographic re-organization linked to the MPT.

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Systematic updates of the agglutinated foraminiferal genus *Colominella* Popescu, 1998: insights from sectioned specimens

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Keywords: agglutinated foraminifera, taxonomy, wall microstructure, Mediterranean Pliocene, Badenian Paratethys.

The occurrence of agglutinated foraminiferal specimens belonging to the genus *Colominella* Popescu, 1998 was documented for the first time by Mancin et al. (2012) in a lower Pliocene record of the western Mediterranean area, thereby extending the known stratigraphical and geographical distribution of the genus previously limited to the middle Miocene (Badenian) of the Paratethys.

Direct comparisons with entire and sectioned topotype specimens of *Colominella paalzowi* (Cushman, 1936), recently sampled in the Badenian type locality of Lãpugiu de Sus (Transylvania), show that the Pliocene individuals from the western Mediterranean morphologically resemble the type species *C. paalzowi* but they also differ in possessing a longer biserial chamber arrangement with a higher number of internal chamber partitions, in lacking a clear early triserial stage, and in having a more complex microstructure of the agglutinated wall, with the grains selected with respect to their size, disposition with the test wall and mineralogical composition. Mancin et al. (2012) interpreted these peculiar shell features as evolutionary adaptations to perform kleptoplastidy and/or to house photosymbionts probably at shallower bathymetries in warm-water environments. The fact that the Pliocene individuals from the Mediterranean appear as more evolved with respect to the Badenian specimens from Paratethys represents an interesting evolutionary development of the genus *Colominella* that begs a further question: are the Pliocene Mediterranean specimens described by Mancin et al. (2012) correctly assigned to the Miocene species *C. paalzowi* or they do represent a new and more highly evolved species?

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Probabilistic approaches for quantitative estimates of past climate change

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Keywords: climate change, quantitative palaeoclimatology, ice-age cycles.

Proxy-based reconstructions of past climate change deliver vital information on the natural dynamics of the ocean-atmosphere-cryosphere system through timescales and climate states that cannot be covered by the instrumental record. Quantitative estimates of the timing, amplitude, and rate of change in relation to climate forcing and feedback processes are the ultimate goal of these proxy-based reconstructions, and more generally of palaeoclimatology. The accuracy of a palaeoclimate reconstruction depends on: (*i*) the analytical protocols; (*ii*) the calibration of each proxy against a specific environmental parameter (e.g., temperature); (*iii*) the chronological frameworks that serve to place proxy records in the time domain; and (*iv*) the associated uncertainties. It remains challenging to use traditional error-propagation techniques to fully account for the multiple sources of uncertainty associated with the multi-step approaches involved in the generation of palaeoclimate reconstructions. I will present an approach based on Monte Carlo statistics, which our team has developed at the Australian National University. It serves to retrieve quantitative reconstructions with rigorous confidence limits from proxy records that have uncertainties associated with both the proxy itself, and the record's chronology. I will then provide an example of this approach, using a suite of geographically distributed proxy records to unravel the sequence of global climate events that characterized the so-called glacial termination II, which separates the penultimate glacial from the last interglacial. Finally, I will discuss how this quantitative analysis of glacial termination II advances the debate on the timing, nature, and magnitude of the ice-volume, ocean, and climate changes that characterized the Quaternary ice-age cycles.

Tibetan Plateau lacustrine sediments as paleofire archives

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Keywords: paleofires, paleoclimate, sediments, biomass burning, PAHs, levoglucosan, Tibetan Plateau.

Biomass burning as a natural process producing greenhouse gases may influence both regional and global climate, and it has become of planetary concern due to anthropogenic activities (Simoneit, 2000; Hopmans et al., 2012; Zennaro et al., 2014). The present work gives information about past fire events in the Tibetan Plateau and helps to increase the understanding of the interaction between Holocene's climate and fire activity. Tibetan Plateau is located in Asia, which is known to be the Earth's largest and most populated continent, and its extension is approximately 1,000 km north to south and 2,500 km east to west, with an average elevation exceeding 4,500 m. We reconstructed biomass burning events of the last 10,500 years recorded in sediments collected from lake Paru Co (4,845 m above sea level), a small moraine dammed lake located on the South-Eastern Tibetan Plateau. Sediment samples were extracted using accelerate solvent extraction and different organic molecular proxies were analysed by GC-MS and IC-MS. We used monosaccharide anhydrides, levoglucosan and its isomers and polycyclic aromatic hydrocarbons as proxies for biomass burning. These are specific molecular markers originated from the pyrolysis of cellulose showing significant fire events and indicate changes in burned fuel. The relationship between this multi-proxy approach and climatic, meteorological and charcoal data allows the reconstruction and contextualization of past fire events and suggests a correspondence between dry climate period and presence of more intense fire events, especially in the Early Holocene.

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The last glacial-interglacial transition in the joides basin and the connected slope-basin system (Western Ross Sea, Antarctica)

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Keywords: Antarctica, Ross Sea, paleoclimate, paleoceanography, sediment cores.

Four sediment cores (ANTA99-cJ3, ANTA95-98C, KI13-C1 and KI13-C2) and two box cores (KI13-bc2 and KI13-bc4), collected in the different geological settings of the Joides Basin-Central Basin area (Ross Sea, Southern Ocean), were studied in the framework of the Italian Antarctic Project (PNRA) ROSSLOPE (Past and present sedimentary dynamic in the ROSS Sea: a multidisciplinary approach to study the continental SLOPE). In this work we consider the time interval spanning from the Last Glacial Maximum (LGM) to the Present in order to investigate the palaeoclimatic and palaeenvironmental evolution of the Western Ross Sea during the last 20ka. Based on the abundance pattern of diatom and foraminiferal assemblages and using integrated proxies (organic carbon, grain size, biogenic silica and CaCO3 content), we document (o constrain) the Ice Sheet retreat history in this sector of the Southern Ocean. We recognized three main phases corresponding to with ice shelf cover, high calving and ice shelf collapse, and seasonally sea ice cover. In addition, the correlation between continental shelf and slope-basin cores allows to identify the environmental evolution of the area during the last glacial-interglacial.

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Paleobiogeography and phylogeny of Rhinocerotini (Mammalia, Rhinocerotidae)

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Keywords: Rhinocerotida, paleobiogeography, dispersal, phylogeny, cladistic, Eurasia, Africa.

The Tribe Rhinocerotini includes the extant rhinoceroses that are currently distributed in limited areas of South-Eastern Asia and Africa. Nevertheless, this Tribe was widely distributed in Eurasia and Africa during the Neogene and Pleistocene. The earliest European representative of the tribe is *Lartetotherium sansaniense*, which occurred during the MN4 (early Miocene). Rhinocerotini are represented by *Rusingaceros leakeyi* and *"Diceros" australis* (both early Miocene in age) in Afro-Arabian continent whereas the tribe occurred in Asia as soon as the early Miocene, with *Gaindatherium* cf. *browni* and cf. *Rhinoceros* sp. (Bugti Hills, Pakistan). The maximal distribution of the tribe occurred through the Plio-Pleistocene. During this time span, the genera *Stephanorhinus* (with seven species) and *Coelodonta* (with four species) were widespread in Eurasia, but they never occurred in the Indian Subcontinent and in the Southeastern Asia (Thailand, Malaysia, Indonesia). The genera *Ceratotherium* (with at least three species) and *Diceros* (with *D. bicornis*) were widespread in Africa whereas the genus *Rhinoceros* (with four species) was limited in the Indian Subcontinent and, together with *Dicerorhinus* (*D. sumatrensis* and *D. gwebinensis*), in the Southeastern Asia. Rhinocerotini have never been recorded in North America. Using the most complete taxon sampling ever for Rhinocerotini, a maximum parsimony analysis (using PAUP*4.0b10) has been performed. Forty-five taxa and 156 characters were considered in these analyses. *Trigonias osborni* was treated as outgroup while a wide set of non-rhinocerotine rhinocerotids (14 terminals) was used as branching group. Within Rhinocerotini, the following minor clades have been recognised: Dicerotina, Rhinocerotina, Dicerorhinina and Coelodontina. The Tribe Rhinocerotini probably origins from late Oligocene representatives of Teleoceratini, but this hypothesis needs to be supported by a deep revision of the latter Tribe. Dicerotina evolved almost exclusively in Africa and the major apomorphies were acquired by the lineage of the genus *Ceratotherium*. Rhinocerotina evolved exclusively in Southeastern Asian and in the Indian Subcontinent. Dicerorhinina was present in Southeastern Asia since the Pliocene but the evolutionary history of this subtribe is still poorly known. Coelodontina was widely distributed throughout Eurasia and the major apomorphies were acquired by *Coelodonta*. Some species belonging to different subtribes acquired similar morphological characters through their evolution (e.g., ossified nasal septum, hypsodonty, reduction of anterior teeth, frontal horn).

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Quantification of sediment fluxes from source to sink during a glacial-interglacial cycle: The Brazos-Trinity depositional system in the Gulf of Mexico

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Keywords: sea-level changes, basin topography, sedimentation, delta, Brazos-Trinity depositional system.

A series of four intraslope basins linked by submarine channels in the northwestern Gulf of Mexico form part of a source-to-sink depositional system that starts in the headwaters of the Brazos and Trinity Rivers and terminates in a ponded intraslope basin offshore Texas—the Brazos–Trinity depositional system. The system is well imaged with 3D seismic data, and two of the basins have been drilled, with three Integrated Ocean Drilling Program wells and two geotechnical wells. Using an integrated approach, we have combined seismic-litho- bio-tephro-stable-isotope-radioisotope stratigraphic methods to generate a millennial-scale resolution chronostratigraphy for this system. Sediment accumulated in the slope basins at rates which varied over time between 1.4 and 55 million tons per year. Except for a short time interval when the Brazos River was diverted to the shelf edge, sediment flux to deepwater was on average less than the present-day sediment discharge of the Trinity–Brazos–Sabine Rivers combined. In the period 24-15 ka the sediment sinks comprising the slope basins and shelf-margin delta can be balanced against the fluvial sources if their discharges are somewhat lower than present day, and if the contribution from incised-valley erosion was relatively small. The history of sedimentation on the slope basins is modulated by sea-level changes, but it is strongly influenced by basin topography and by the dynamics of delta development on the shelf. During peak high stands of sea level the slope area receives only pelagic sediments; during low sea-level stands, the sedimentation in each basin results from a complex combination between fluvial input at the head of the first basin, and the rate of subsidence/sedimentation causing basin topography. The ages of sediments in separate basins show that sedimentation occurs at the same time in multiple basins with trapping of sand in updip basins, while mud is preferentially deposited in downdip basins.

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Basin evolution in the Carnic Alps between the upper Lochkovian and the lower Famennian

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Keywords: upper Lochkovian, lower Famennian, Carnic Alps.

The Carnic Alps, spreading along the boundary between Austria and Italy, correspond to the non- to low-metamorphic portion of the Variscan substratum of the Southern Alps, and display an Upper Ordovician to Upper Carboniferous succession that represents the best preserved example of Variscan succession within the Alps. This area has been recently object of a project aimed to align the lithostratigraphic units definitions and names which were often different in the Austrian and Italian nomenclatures and then to formalize them in a unified stratigraphic scheme (Corradini & Suttner, 2015). The present work is an outcome of this project.

The upper Lochkovian to Frasnian stratigraphic interval is characterized by the differentiation of the basin in shallow water, including carbonate buildups, and pelagic parts, separated by the so-called 'transitional facies', that represent a sort of 'connection' in between.

We analyzed the depositional evolution of the basin through these latter facies because they reflect well the depositional dynamics, are datable using conodonts, unlike the shallow water units and are less subject to tectonic elisions/repetitions than the basinal units. We performed geological mapping, measured stratigraphic sections of all the units and dated by conodonts all the lithostratigraphic transitions, in order to infer the lateral correlations throughout the basin, also supported by some marker beds/levels (including anoxic events). The depositional environments of the different units have been recognized.

The main aspects of the basin evolution can be summarized as follows. A transgression around the uppermost Lochkovian-Pragian boundary (Lochkov-Prag Event?) drowned the first patch reefs recorded in the Carnic Alps. During the Pragian patch reefs re-established. The margin was ramp-type until the Emsian with patch reefs and shoreface deposits distally passing to tempestite and pelagic sediments. During the Emsian, a steeper slope margin separating the shallow water (including extensive reef) and the basin started to develop as shown by the increasing amount of gravity-driven deposits that persisted until the lower Famennian. Higher frequency transgressive-regressive pulses probably controlled the emplacement of black shales corresponding to the Kačák event. In the lower Givetian the gravity-driven deposits show their maximum progradation on top of the basinal deposits. From the Frasnian, combined extensional or transtensional tectonic activity and eustatic fluctuations led to carbonate buildups disappearance.

The depositional evolution appears to reflect the supra-regional eustatic trends until the Frasnian. From the Frasnian, the importance of a local tectonic control appears to increase, even if global trends are sometimes still recognizable.

Corradini C. & Suttner T. J. (eds.) 2015. The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Bundesanstalt, 69, 158 pp.

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Ostracods as a possible lecture key to explicate past carbonate deposition phenomena in the Ross Sea-Antarctica

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Keywords: Antarctica, Ross Sea, Ostracods, Carbonate deposition.

Carbonate-producing marine organisms are sensitive to changes in temperature, light, suspended mud, nutrient availability and hydrodynamics. For all these reasons, the fossil assemblages of marine sediments contain invaluable proxies useful to reconstruct the evolution of marine ecosystems. In this sense Quaternary carbonate deposits on modern polar shelves, neither abundant nor aerially extensive, are nonetheless important as they provide unique information about marine shelves at latitudes that are particularly sensitive to global change. Within fossil assemblages, Ostracods have an excellent fossil record and are among the few groups that can be palaeo-environmentally informative in the marine realm and so are widely employed as a palaeoclimatic indicator. The NW Ross Sea area close to Cape Adare shows carbonate-rich lithofacies, consisting of poorly sorted sandy and gravelly skeletal remains with a good presence of biological remains. The high abundance of fossil ostracods is related to the water mass circulation with related changes in nutrient content, salinity, sea ice cover and $CaCO_3$ saturation. Seven gravity cores recovered during two PNRA cruises were investigated: a) to define different accumulation patterns in the western Ross Sea area where carbonate rich sequences associated with glacial marine sediments were recovered; b) to locate the more or less favorable periods when carbonate factories operated in order to produce carbonate sediment c) to exploit qualitative and quantitative variations of the ostracod species together with compositional data to reconstruct the ice shelf-front oscillation phases. Preliminary results of the cores showed strong qualitative/quantitative variations on ostracod populations probably linked to specific glacial fluctuations. The species which are almost constantly present throughout the cores are: *Australicythere sp., Cativella bensoni, Cytheropteron antarcticum, Echinocythereis sp., Loxoreticulatum fallax, Krithe sp., Pseudocythere cf. P. caudata, Patagonacythere sp*. These species have been frequently recorded as dominant elements in modern Antarctic shelf environments. Some levels of the cores, characterized by high terrigenous inputs, show an evident decrease in the number of ostracods, mainly *Echinocythereis sp., Loxoreticulatum fallax and Krithe sp*. Cores collected on the top banks usually show a gradual increase in ostracod diversity, a trend that continues more uniformly from bottom to top, at the same time highlighting high percentages of test fragmentation thus reflecting reworking phenomena. The results provided information which confirms that micropaleontological analyses based on the ostracods of the Ross Sea will help to improve our understanding of the carbonate deposits in polar settings and will be an excellent instrument to obtain a sharper interpretation of the paleoenvironmental and climatic changes which affected the Ross Sea area during the last glacial events.

Cenozoic temperature and oceanographic evolution of the tropical Atlantic Ocean

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Keywords: Cenozoic, tropics, sea surface temperature, polar amplification, TEX86, dinoflagellates.

Recent high-resolution records of deep ocean benthic foraminifer oxygen isotope ratios beautifully document the Cenozoic evolution of deep ocean temperatures and continental ice volume on orbital time scales. These records are often interpreted to reflect global climate, but (sea) surface temperature (SST) records from meridional transects are required to document global change, and vital aspects of climate such as polar amplification, as well as associated oceanographic and biotic changes. Decent surface temperature records from mid and high-latitude regions are available for much of the Cenozoic but reliable tropical records are rare.

Here we present late Paleocene to Pliocene SST, oceanographic and biotic records mostly based on TEX86 biomarker paleothermometry and organic dinoflagellate cyst assemblages from Ocean Drilling Program Site 959 in the eastern tropical Atlantic from the. Along with the long-term trend, we identify changes across the Paleocene-Eocene Thermal Maximum (~56 Ma), the Middle Eocene Climatic Optimum (~40 Ma), the Middle Miocene Climatic Optimum (~16 Ma), and the Pliocene Warm Period (~3 Ma). The records suggest that tropical temperature trends and variability typically mimics high latitude and deep ocean trends. Although aspects of the record can be related to regional oceanographic processes such as upwelling, we use comparison to deep ocean and high latitude records to reconstruct polar amplification of climate change from the early Paleogene greenhouse, to the Neogene icehouse.

Massive remobilization of permafrost carbon during post-glacial warming

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Keywords: Younger Dryas, permafrost, Arctic, deglaciation.

Recent hypotheses, based on atmospheric records and models, suggest that Permafrost Carbon (PF-C) accumulated during the last glaciation may have been an important source for the atmospheric CO_2 rise during post-glacial warming. However, direct physical indications for such PF-C release have so far been absent. Here, we use the Laptev Sea (Arctic Ocean) as an archive to investigate PF-C destabilization during the last glacial-interglacial period. Our results show evidence for massive supply of PF-C from Siberian soils as a result of severe active layer deepening in response to the warming. Thawing of PF-C must also have brought about enhanced organic carbon respiration and, thus, these findings suggest that PF-C may indeed have been an important source of CO_2 across the extensive permafrost domain. The results challenge current paradigms on the post-glacial CO_2 rise and, at the same time, serve as a harbinger for possible consequences of the present-day warming of PF-C soils.

SESSION S17

Dynamics of carbonate systems: from facies analysis to global changes

CONVENERS AND CHAIRPERSONS

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Seismically-induced soft-sediment deformation structures in Upper Triassic deep-water carbonates (Central Sicily)

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Keywords: soft-sediment, deformation structures, synsedimentary tectonics, Upper Triassic, deep-water carbonates.

We describe soft-sediment deformation structures into the Upper Triassic cherty limestone outcropping in the Pizzo Lupo section (Central Sicily, Italy), pertaining to the deep-water palaeodomain of the Southern Tethyan margin.

In the study section, mainly consisting of thin-bedded mudstone/marl alternations with bedded chert intercalations, some lithofacies have been separated on the basis of the abundance of the calcium carbonate/clay content and the overall textural features.

The deformational structures, displaying different deformational styles as folded and faulted beds, disturbed layers, clastic dikes, and slumps occur mainly in the deformed horizons that involve marl-dominated lithofacies. Small-scale water-escape structures involve beds with nodular fabric. Synsedimentary faults affect the mud-limestone dominated lithofacies, which are characterized by fault-rotating blocks producing lateral thinning. These bodies appear to have moved coherently along an overall planar surface.

We relate these soft-sediment deformations to slump sheets, associated with down-slope sliding of sedimentary masses. The deformation mechanism and driving force for these soft-sediment deformations are due essentially to gravitational instability and dewatering.

Detailing, rotational (slump) and translational (glide) slides and water-escape are the main processes causing the distinguished deformational styles.

The synsedimentary extensional tectonics that affected the Upper Triassic pelagic deposits was the triggering process responsible for the instability of the seafloor inducing loss of coherence of the unconsolidated sediments on the sea bottom, developing a large number of gravity-driven slides.

The analysis of both of these SSDSs and their relationships with the structural scenario allow us to hypothesise that they are seismically-induced.

Role of compaction-induced subsidence on the creation of accommodation space at the top of a prograding carbonate platform: constraints from numerical modelling (Esino Limestone, Triassic, Southern Alps, Italy)

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Keywords: Carbonate platform, Triassic, paleokarst, terra rossa soil, accommodation, differential compactio

The demise of the high-relief, steep slope, prograding Ladinian-Early Carnian carbonate platforms of the Esino Limestone (Central Southern Alps of Italy) is marked by subaerial exposure of the platform top associated with different erosional (mainly karst-related), depositional and diagenetic processes (Calcare Rosso Fm.). The exposure-related deposits consist of three major facies associations: 1) residual soils with thin lenses of conglomerates with black pebbles, up to 5 m thick, and, locally, weathered vulcanites; 2) chaotic breccia lenses irregularly distributed in the uppermost part of the Esino Limestone carbonate platform, interpreted as collapse breccias in karstic setting: 3) inter-supratidal carbonate cycles with dissolution and development of paleosols and tepee structures (up to 60 m thick).

Facies distribution follows the sub-environments of the underlying Esino Limestone. Facies 1 and 2 typically characterize the core of the platform, covering the underlying inner platform facies. Facies 3 instead develops toward the edge of the platform, above reef-upper slope facies of the prograding facies of the Esino Limestone. The thickness of facies 3 decreases toward the core of the platform. Facies distribution reflects differences in the accommodation space and sedimentary processes from the rim (highest accommodation, favouring the deposition of peritidal-supratidal carbonates) to the core (reduced accommodation, causing pedogenesis and karstification) of the carbonate system.

The observed changes in thickness may reflect different controlling factors: 1) syndepositional tectonics, 2) differential subsidence controlled by subsidence induced by magmatic activity or 3) differential subsidence controlled by the stratigraphic architecture of the Esino Limestone platform and adjoining basins. As evidence of tectonics was not observed and the presence of volcanic bodies is only documented tens of km away from the study area, the scenario involving the creation of accommodation space by compaction of the basinal sediments (resedimented, fine-grained calciturbidites) during the progradation of the carbonate platform is here investigated. Numerical modelling was performed to verify the compatibility of compaction-induced subsidence with the observed depositional architecture. The models were built to simulate the evolution (aggradation and progradation) of the platform by progressively adding layers from deepest to shallowest, while compacting the underlying sediments, in order to evaluate compaction-induced subsidence (and accommodation space for the Calcare Rosso limestone) after the deposition of the youngest platform strata. Modelling results allow us to conclude that the wedge shaped shallow-water Calcare Rosso Fm, deposited on top of the extinct Esino carbonate platform, can be explained by differential compaction-related subsidence associated with the fast progradation of platform slope deposits on top of highly compactable deep-sea sediments

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New insights on the sedimentological and biostratigraphic record of the Upper Cretaceous of the Salento Peninsula (Apulia, Southern Italy): collecting data from an abandoned quarry near Manduria

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Keywords: Apulia Carbonate Platform, Upper Cretaceous limestones, "Plattenkalke"-type deposits.

The analysis of vertebrate material from the Salento Peninsula (Italy), currently stored at the Museum of Paleontology of the University of Rome 'Sapienza' and the Natural History Museum in Verona, led us to conduct a preliminary field survey and prospection in order to localize suitable outcrops for paleontological excavations. As a result, new stratigraphic and sedimentological features of the Cretaceous limestones of the Apulian Carbonate Platform are here reported. The attention was focused on the northern sector of the Salento Peninsula, and in particular on an abandoned quarry about 2 km NE of Manduria (Taranto, Italy). About 8 meters of Upper Cretaceous '*Plattenkalke*'-type deposits referable to the Calcare di Altamura Fm., showing interesting paleontological and geological aspects, are here exposed. A high-resolution litho-biostratigraphical study of the succession was performed at a mm-scale in order to reconstruct the paleoenvironment setting of the area.

From a stratigraphic and sedimentological point of view, the lithotypes outcropping in the quarry are dominated by the cyclic alternation of: i) mm- to cm-thick, dome-shaped, cyanoalgal laminites, sometimes cross-cut by mud-cracks; ii) 'fenestral' horizons made of prismatic-to-discoidal voids, in some cases larger than 1 cm, related to dissolution of evaporitic salts (mainly sodium chloride); iii) wedge-shaped pedogenetic horizons (*terre rosse)* and paleokarst structures, sometimes associated with syn-sedimentary tectonics.

From a paleontological point of view, a unique and well-preserved thanatocoenosis characterizes the studied succession. The macrofauna is strictly oligotypic and consists of fish-remains, coprolites, regular sea urchins and few specimens of *Chondrodonta* sp., while the microfauna is totally absent. The main feature is represented by the kind of preservation of the echinoids and their spines. In fact, echinoids are preserved as "ghosts", with the original high-Mg calcitic test completely leached. The moulds are partially filled by yellow-orange silt and clay, referable to incipient paleokarst features, or by crusts of microcrystalline calcite. Furthermore, a large number of isolated radioli were found, while no echinoid tests with articulated spines were recovered.

The facies analysis of the "vuggy" and laminated limestones suggests a saline and dry, supratidal mudflat-type setting as depositional environment. Hypersaline conditions are highlighted by salt-rich levels, while periodical and ephemeral flooding of normal-salinity seawater allowed the colonization of the sea floor by benthic organisms (mainly echinoids), and occupancy by fishes. Extreme conditions of the depositional setting are marked by the total lack of the microfauna. Finally, the occurrence of occasional wet phases also led to the development of soils and karstic phenomena.

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How the "Monterey Event" controlled carbonate platforms evolution: the central Mediterranean case history

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Keywords: Miocene, Central Apennines, Monterey Event, carbon isotopes.

The middle Miocene is a key time interval for studying and understanding the modern global climate evolution and its consequences on marine systems. It is characterised by the Mid-Miocene Climatic Optimum (MMCO), when water temperatures at mid-latitudes were 6 °C higher than today (Flower, 1999). It coincides with a huge, long-term carbon isotope positive shift, known in literature as "Monterey Event" (Zachos et al., 2001). This global climatic and trophic shift deeply affected carbonate production. In this work we present a lower to middle Miocene carbon isotope record from two different carbonate platforms included in the central Apennines: the Bryozoan and *Lithothamnion* Limestones (Latium-Abruzzi Platform), and the Bolognano Formation (Apulian Platform) records. The Monterey Carbon Isotope Excursion has been identified in both the analysed successions. A detailed biostratigraphic analysis, together with the age constraints provided by the Sr isotope stratigraphy for the Latium-Abruzzi carbonate platform record, allowed us to correlate our data to the $\delta^{13}C$ oceanic record, at least for two of the six well known $\delta^{13}C$ maxima recorded in the lower to middle Miocene interval. In the studied platform settings, the Monterey Event coincides with a spread of bryozoans in middle to outer ramp environments. The proliferation and expansion of filter feeding organisms, as the bryozoans, should have been linked to persistent high trophic conditions, enhanced by regional factors that occurred in the Burdigalian-Langhian time interval, such as the closure of Indo-Pacific connection, the Sardinia-Corsica volcanism and the Apennine orogenesis. The evolution of the central Apennines carbonate ramps is strongly influenced by the trophic conditions. In fact, the high productivity of the bryozoan-dominated factory in the aphotic zone had an important control on the overall depositional profile of the platforms, leading to the development of low-angle ramps.

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Carbonate precipitation associated with benthic microbial communities in active thermogene travertine systems from Central Italy

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Keywords: travertine, microbial carbonates.

The study of travertines forming in active hydrothermal systems contributes to the understanding of the interaction between physico-chemical processes (CO_2 degassing and cooling of flowing thermal water) and the role played by microbial biofilms in mediating and influencing carbonate mineral precipitation. Three active travertine systems were investigated in Central Italy to identify the carbonate meso- and micro-scale precipitated fabrics and the associated microbial communities at varying thermal water temperature.

Samples from the Bullicame (Viterbo) travertine mound derive from a 20-40 cm-wide channel with water temperature varying from 55°C to 50°C along a 60 m distance; pH increases from 6.7 to 7.4 along the channel, whereas alkalinity decreases from 15.6 to 14.5 meq/l due to CO_2 degassing and carbonate precipitation. The proximal channel centre is colonized by carbonate encrusted fans of filamentous microbes (sulphide oxidizing bacteria); the margins and the distal channel portions are draped by green to orange microbial mats with calcified gas bubbles and rafts.

The temperature of Bagni San Filippo (Tuscany) vent is 46-49.5°C; pH increases from 6.5 at the vent (alkalinity 31.6 meq/l) to 7.3 nearly 14 m downstream, where temperature drops to 41.4°C and alkalinity to 21.5 meq/l. Carbonate precipitates consist of centimetre-size terraces, rafts, coated gas bubbles and millimetre-size dendrites associated with green microbial mats.

The Gorello (Saturnia, Tuscany) travertine terraced slope system consists of metre-scale horizontal pools separated by decimetre-high walls. Water temperature is 33°C and alkalinity 9.1 meq/l; pH values increase from 7.7 to 7.9 in the flow direction. The pool rims and walls are coated by green microbial mats; centimetre-size oncoids coating detrital grains form within the pools.

At the microscale, carbonate precipitates are similar in the three settings and characterized by seed-shaped calcite crystals (5-20 μm) organised in radial spherulitic structures surrounded by biofilm EPS (Extracellular Polymeric Substances). The lower temperature Gorello system is also characterized by nanometre-scale calcite precipitates aggregating in micron-size micrite clots associated with filamentous cyanobacteria. Despite similar microscale precipitates, microbial communities are different as a function of varying temperature: a) high temperature communities (55-49°C) of filamentous and rod-shaped sulphide oxidizing bacteria, b) intermediate temperature communities (50-40°C) dominated by *Spirulina* cyanobacteria, c) low temperature (38-30°C) communities of filamentous cyanobacteria, including *Phormidium*, sparse *Spirulina* and diatoms. This study demonstrates that microbial communities in travertines vary as a function of water temperature; carbonate precipitation, driven by thermal water degassing, is influenced by microbial biofilm acting as low-energy substrate for crystal nucleation or it takes place within the biofilm EPS.

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Effects of the S-P Event (Sinemurian-Pliensbachian, Early Jurassic) on the Trento Platform: evidences from the Lombardian basin and similarities with the Carnian Pluvial Event (Upper Triassic)

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Keywords: S-P Event, stable isotopes, carbonate platform crisis, Early Jurassic.

In the Early Jurassic, the paleogeography of the western Tethys was that of a series of fault-bounded highs and lows. On one of these highs, the Trento Platform, now exposed in the Southern Alps, the shelf carbonate succession of the Calcari Grigi Group deposited from the Hettangian to the late Pliensbachian. The Trento Platform records a first deepening of the sedimentary environments in correspondence of a $\delta^{13}C$ negative perturbation, the so-called "*arnioceras* event", occurred in the middle part of the Sinemurian (Masetti et al., 2016). After that, the depositional system in the inner platform switches from a peritidal flat (Monte Zugna and Loppio Oolitic Limestone Formations) to a lagoon (Rotzo Formation). This change occurs around the Sinemurian-Pliensbachian boundary when a major negative $\delta^{13}C$ shift recorded globally by marine carbonates and wood, named S-P Event, is documented (Korte and Hesselbo, 2011). In this contribution a new $\delta^{13}C$ isotope record from the deep-water sediments deposited in the Lombardian basin, whose age is constrained with nannoplankton biostratigraphy, is presented. Quantitative petrography (modal analysis) has been carried on calciturbidites. A prominent negative carbonate carbon-isotope shift that can be referred to the S-P Event is highlighted. Across the $\delta^{13}C$ spike, a decrease of the material exported from the platform and a change in the composition of calciturbidites, from microoncoids-dominated to skeletal grains-dominated, are observed. On the platform, the first part of the S-P Event is elided by a subaerial exposure surface, followed by the deposition of marly limestones that testify for an increase of terrigenous input into the lagoon, and by the onset of meso-eutrophic conditions. We interpret this evolution as the expression of a crisis in the carbonate production of the Trento Platform across the S-P Event, coupled with a climate change towards more humid conditions. The sedimentary evidences recorded in correspondence of the S-P carbon-cycle perturbation on the Trento Platform are also compared to those documented at the Carnian Pluvial Event (early Late Triassic) in the Dolomites, with whom they share close similarities.

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Carbonate sequence stratigraphy: an intriguing challenge or an hazardous tool?

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Keywords: Sequence stratigraphy, carbonates.

Sequence Stratigraphy is an integrated and multi-disciplinary approach to the investigation of depositional systems that has deeply influenced the researchers in the last tens of years. The sequence stratigraphic framework applied to carbonate depositional systems provides one of the major tools for the understanding and prediction of facies associations and geometric architectures. Differently to siliciclastic system, carbonates cannot be described or limited only in terms of changes in accommodation, sedimentary supply and climate. In fact, carbonate sediments do not come from a source external of the depositional system, but they are mostly produced in situ (e.g. *autochthonous* and *parautochthonous carbonates)*. Moreover, carbonate sediments are sensitive to water chemistry, pCO_2, temperature, nutrients, biota, and other environmental forcings. Furthermore, during fast subsidence phases, the impressive capacity of carbonate platforms to keep up might lead to a misinterpretation of the hierarchic order of the depositional cycles or sequences. A similar problem derives from the high sensitivity of carbonate platform systems to small eustatic variations.

Hence, sequence stratigraphy applied to carbonate depositional systems needs a deep investigation of all these controlling factors, in particular which the carbonate sediment supplier is, where it is physically produced and how it is transported.

The stratigraphic record of Mediterranean Meso-Cenozoic carbonate platforms is an amazing laboratory for testing carbonate sequence stratigraphy in different settings and with different depositional systems, from M to T to C factories over a period of 250 Ma. In particular, a stunning laboratory is the Triassic succession of the Southern Alps, which permits to compare the response of carbonate, terrigenous and mixed systems to relative sea level variations within a high-resolution bio-chronostratigraphic framework.

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3D stratigraphic forward modelling of the Upper Jurassic Arab Formation: an onshore Abu Dhabi (UAE) case of study

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Keywords: 3D startigraphic forward modelling, carbonate ramp, Arab Formation.

During the Upper Jurassic (Kimmeridgian-Tithonian) the Arab Formation (Fm) was deposited across the Arabian Platform, characterized by the cyclic deposition of shallow marine carbonates and evaporites. The formation is well known as it includes one of the most prolific reservoirs in the world, but it has undergone a complex depositional-diagenetic history, therefore additional studies on stratigraphy/facies analysis are required for future assessments of the diagenetic effects on the reservoir properties. In the area of study, the Arab Fm corresponds to a shallow marine ramp made up of prograding oolitic shoals protecting a restricted lagoonal area, overlain by a series of evaporites deposited in a sabkha setting. For this work, five wells onshore Abu Dhabi were made available to develop a field-scale conceptual model for the Arab Fm, based on a sequence stratigraphic framework, obtained by the combination of cores, petrographic, and well log analyses. To validate the conceptual model and try to predict the heterogeneities of the depositional system, a 3D diffusion process-based stratigraphic forward modelling was used as a powerful tool to simulate the spatial distribution of facies, unraveling and testing different scenarios. The modelling investigates the interplay between different sedimentary processes, in order to quantify the parameters that impact and control the sedimentation within a basin. The main input data tested were: i) the carbonate production; ii) the eustatic variations; and iii) the subsidence. The obtained output models were calibrated with the well data (in terms of alternation of facies and thickness of the different sedimentary units). The models were displayed according to different time intervals, that showed the step by step evolution of the sedimentary infill, helping in the prediction of the Arab Fm stratigraphic framework between the wells and in the portions of the studied area distant from the available wells.

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Cyclic Life of Shallow-Water Carbonate Platforms along Oceanic Fracture Zones

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Keywords: Shallow-water carbonates, oceanic islands, Oceanic Fracture Zones.

Shallow-water carbonates formed on top of oceanic islands are strongly controlled by their geodynamic context. Oceanic islands have been divided into two classes: "Volcanic" islands, due to excess volcanism caused by melting anomalies in the suboceanic mantle (Wilson, 1963) and "tectonic" islands, made of uplifted blocks of oceanic lithosphere due to transform tectonics. (Bonatti, 1977).

Short-lived carbonate platforms have been identified on top of sunken oceanic tectonic islands along transverse ridges flanking the Vema and Romanche transforms (Bonatti et al.1983, Gasperini et al., 1997; Palmiotto et al., 2013). They consist of slivers of oceanic lithosphere, exposed above sea level and successively capped during Middle-Late Miocene by rhodalgal-dominated carbonates (Corda and Palmiotto, 2015). A modern example of oceanic tectonic island capped by a poor shallow-water biota association, is St. Paul' Rocks, along the St. Paul transform (equatorial Atlantic).

We compare sunken and modern islands from the central Atlantic with the Cayman and Swan Islands, aligned along major Caribbean transform faults, in order to evaluate similarities and differences in the sedimentary architecture of their carbonate platforms.

The carbonate platforms developed on top of oceanic tectonic islands, unlike those on top of volcanic islands, record a "cyclical" evolution, with stages of uplift-emersion-erosion-subsidence-deposition triggered by de-activation-reactivation of tectonic forces along oceanic fracture zones. Moreover, the strong vertical tectonics and high seismicity in tectonic islands and their elongated and narrow shape control geometry and biota associations of the carbonate platforms limiting coral reef development, in contrast with the luxuriant reefs of volcanic islands, and favoring the growth of rhodalgal-foramol biota associations even in the tropical/equatorial realm.

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Origin of facies zonation along the slope of the Middle Triassic Latemar carbonate platform (Dolomites, Italy): clues from trace element and stable isotope geochemistry

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Keywords: REE, stable isotopes, oxygen minimum zone, carbonate platform, Triassic.

Many Paleozoic and Mesozoic high-relief carbonate platforms show a subdivision of the slope facies. The upper slopes are comprised of massive to poorly clinostratified microbial boundstone, whereas clinostratified deposits of grainstone, rudstone, and breccia are common lower slope facies. At present, the reasons why such slope facies subdivision exist are not fully understood, and the environmental conditions along these slopes are only poorly constrained.

In order to shed light on the origin of the facies zonation of microbial platforms, marine fibrous cements lining cm-scale primary cavities were sampled along a well exposed slope of the Latemar platform at different paleo-water depths, and were analyzed for their C and O stable isotope composition. Rare earth element (REE), Y, Ca, Mg, Fe, Mn, Cr, Co, Cd, Cu, Ba and Sr contents were also analyzed, using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS).

The fibrous cements are characterized by superchondritic Y/Ho ratios, negative Ce anomalies and PAAS-normalized patterns that are depleted in light REE, indicating precipitation in oxygenated seawater. The highest $d^{13}C$ values were recorded in samples from shallow depths, and then reach a minimum at paleo-water depths of around 50-200 m. Cadmium (Cd), a trace metal with a nutrient-like behavior, is most abundant within this same depth range. A correlation between $d^{13}C$ and Cd points to an active biological pump in the water column flanking the slope. Photosynthesizing primary producers were active in the first few tens of m of the water column, as reflected by relatively higher $d^{13}C$ carbonate values. A respiration maximum is indicated between 50-200 m water depth by relatively high Cd, and a $d^{13}C$ which is ca. 0.5 ‰ lower with respect to the surface water. Below 200 m water depth, Cd and $d^{13}C$ values rebound, and slope facies switch from microbialitic to detrital (grainstone and rudstone). The correlation of nutrient tracers with the downslope facies transition suggests that the microbial communities that constitute the boundstone facies were likely nutrient-limited at Latemar, and could only proliferate at shallow water depths, where nutrients were not yet depleted by respiration. This could explain the subdivision of the slope into a upper (microbial) and a lower ("detrital") facies belt, and suggests that this facies transition, commonly observed in Paleozoic and Mesozoic microbial platforms, may mark the depth to the oxygen minimum zone in coastal water columns.

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Sedimentology and biostratigraphy of a peritidal succession across the Triassic/Jurassic boundary: Monte Sparagio, north western Sicily

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Keywords: T/J boundary, perital carbonates, foraminiferal biostratigraphy, Sicily.

A 490 m thick section of shallowing upward peritidal cycles spanning the Triassic-Jurassic boundary is exposed along the northern slope of Mount Sparagio in the San Vito Lo Capo Peninsula (Western Sicily). A detailed microfacies analysis allowed defining the aspects of cyclic sedimentation of this section and especially the stratigraphic occurrence patterns of benthic foraminifera and algae across the T/J boundary.

The lower part of cycles commonly shows medium to low energy subtidal facies, typical of the inner lagoon of the carbonate platform. Subtidal facies such as coral bafflestone in some cycles suggest more open lagoonal conditions (patch reefs), while some higher energy layers such as ooidal grainstones or megalodont rudstone/floatstones are interpreted as storm layers. The intertidal facies consists of planar stromatolites and loferites, while the upper part of cycles is commonly composed by flat and black pebbles conglomerates capped by Terra Rossa paleosols.

The thickness of cycles is quite irregular and reflects irregular variations of accommodation space on the flat topped platform. It ranges from a few tens of cm to 3-4 m (in case of the presence of thick paleosols), with an average thickness of about 1-1.5 m. Often, the upper part of the cycles and, in particular, the paleosols, is truncated by a ravinement surface generated by the periodic flooding of the platform.

The distribution pattern of megalodontids allows to differentiate three different informal units: a lower unit containing abundant and large megalodontids (A unit); an intermediate unit characterized by small and rare megalodontids (B unit) and an upper unit lacking pelecypods (C unit).

The foraminiferal assemblages in the units A and B (*Triasina hantkeni, Aulotortus permodiscoides, Glomospirella friedli, Aulotortus sp.*) match the *Triasina hantkeni* range zone. Upsection, the abrupt disappearance of all the benthic foraminifera in the subtidal units and the onset of an oligothipic association dominated by *Thaumatoporella parvovesiculifera,* is assumed as the Rhaetian/Hettangian boundary. A gradual recovery of benthic associations is documented upsection by the appearance of siphovalvulinids such as *Siphovalvulina gilbraltarensis.*

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The response of mid-Cretaceous shallow water carbonate factories to the climatic/oceanographic events: case study from central-southern Apennines (Italy)

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Keywords: Mid-Cretaceous, shallo water Limestone, carbonate factories, global changes, central-southern Ape

The mid-Cretaceous represents one of the classical "Greenhouse" period in the history of planet Earth. Intensive volcanic activities, major sea level rise, high CO_2 partial pressure, carbon cycle perturbations, marine organisms turnover and possibly different oceanic current systems and no major ice caps in north and south poles are characterized this time slice of geological time scale. Since carbonate rocks are product of oceanic/climate systems therefore carbonate platforms represent one of the most important archive in the Cretaceous period and could be invoked to understand more about climate and oceanic/atmospheric systems in the past times.

Extensive studies have been focused on (hemi)pelagic and outermost shelf environments to decipher causes, effects and consequences of OAEs. By contrast, the shallow water environments have received less attention regarding to the overall response to environmental changes linked to oceanic anoxia and consequent paleoecological conditions

In order to document and decipher more about the mid Cretaceous, we have selected central-southern Apennines (Italy) carbonate sequences ranging from the Latest Barremian to the Early Albian, analyzed by means of a multidisciplinary approach including detailed biostratigraphy, sedimentology and litho-bio facies analysis, and stable carbon and oxygen isotopes. This allowed identifying six intervals characterized by specific trends. The detailed bed-by-bed analysis enabled us to trace lateral and vertical sedimentation patterns inside the above intervals.

The studied limestones were deposited in shallow water systems lacking clear drowning events or biological crises leading to severe carbonate factory extinctions. Nevertheless, remarkable and synchronous drops in the biotic component characterize the recognized units. The shift in the biotic assemblages and the outbreak of particular organisms indicate the recurrence of significant conditions of stress in the water mass resulting in repeated carbonate factory decline episodes. The recovering of the carbonate factory occurred by means of benthonic communities showing characteristic trends and resulted in new sedimentary carbonate systems whose biotic assemblages markedly diverged from the former ones.

Two mains gaps characterise the analysed successions. The first gap is witnessed by an erosive surface; the second one is marked by a sharp variation on the stratal pattern characterizes the related boundary, marked in the field either by a well developed erosion surface or by repeated exposure surfaces marked by microkarst and incipient pedogenesis.

The analyzed successions document the coupling of significant tectonic and general climate control on the sedimentary patterns. The facies analysis, compared with the geochemical data and the biostratigraphic constrain, well supports the climatic interpretation deriving from the paleoecological meaning of the recognized biotic and facies assemblages.

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The inception stage of a high relief carbonate platform (Esino Limestone, Southern Alps of Italy): facies, architecture and depositional processes

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Keywords: Inception stage, High relief carbonate platform, middle Triassic.

High-relief carbonate platforms evolve from a poorly known nucleation stage that has different environmental conditions and depositional processes with respect to the mature stage of the platform. To understand the processes that lead to the development of a high-relief carbonate platform, it is crucial to analyze facies type and distribution during the early phase of their development.

The Esino Limestone (up to 800m thick, with a final platform-to-basin relief of 550 m) preserves exposed the inception stage deposits. In its mature configuration the carbonate system was characterized by a wide inner platform (bedded peritidal limestones with stromatolites, oncoids, fenestrae and dasycladaceans), bordered by a narrow reef (*Tubiphytes* and microbial mounds associated with coral framestones with calcisponges and intrabioclastic packstone) that sourced the breccias of the steep slopes.

20 stratigraphic sections have been measured and about 550 samples for microfacies analysis have been collected in the 30-130 meters-thick succession of the nucleation stage. Facies type and distribution led to the stratigraphic reconstruction and to the identification of major phases in the early platform evolution, which are linked with relative sea-level changes. A first transgression, following the drowning of the antecedent peritidal platform (Camorelli Limestone), is characterized by the deposition of dark bioturbated bio-intraclastic packstone and wackestone passing to bedded black marly limestones and marls (Prezzo Limestone). A general regressive trend, with an interposed minor transgression, is characterized by intraclastic packstones and decreased terrigenous input. Sparse reefal bafflestones (porifera, algae, corals, *Tubiphytes*) and peritidal facies (stromatolitic bindstone with fenestrae, early marine cements, intrabioclastic packstone) record the final onset of the core of the future high relief carbonate platform. The end of the inception stage is thus controlled by the progradation of sparse patch reefs that fill up the depositional space, leading to the coalescence of isolated small nuclei of carbonate production.

This study documented the key role played by antecedent topography and sea-level changes in the localization and growth of the first platform nuclei. Furthermore environmental conditions (e.g. terrigenous input, water circulation) possibly exerted a control on the organisms associations that characterized the first stages of platform evolution.

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Stratabound porosity in peritidal carbonates: an interplay between bioturbation, relative sea- level fluctuations and mixing-water dissolution

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Keywords: Carbonate platform, stratabound dissolution, spongy-like porosity, Triassic, Sicily.

The analysis of a paleokarstic system hosted by peritidal carbonates in north-western Sicily, allows to differentiate multi-scale dissolution events that affected the carbonate platform interior during the uppermost Rhaetian. Among other types of dissolution morphologies, the Triassic cycles show extensive phenomena of stratabound dissolution that can be grouped into three main types: vug, moldic and "spongy-like". The dissolution features are particularly concentrated in the subtidal members of cycles. The creation of different types of porosity appears to be mainly controlled by the textural characters of the host-rock. In particular the cm-scale bioturbation in muddy sediments, probably operated by crustacean decapods, results as the most important factor in determining the spongy-like pattern. Regarding the dissolution fluids responsible of the stratabound porosity, the morphological comparison of the spongy-cavities with recent analogues from modern carbonate platforms, coupled to geochemical data, supports a dissolution by the influence of mixing water.

On the base of collected data, we speculate on a possible model to explain the formation of the observed stratabound dissolution. It implies an interaction of several controlling factors at the interface between marine and meteoric diagenetic realms during the relative cyclic oscillations of sea-level. The presence of a fresh water supply from an adjacent emerged area is the key for the periodic formation of a mixing water lens during the relative sea level lowstand that brought about the subaerial exposure of the platform.

The resulting dissolution pattern in the subtidal unit of a specific cycle is strongly controlled by the textural features of the sediments. In the case of bioturbated wackestones the 'spongy' (also known as 'swiss-cheese') pattern develops, while in mollusk-rich beds biomoldic porosity occurs. In well-sorted subtidal members, such as algal grainstones, the dissolution originates as randomly distributed vuggy porosity. During the periodic flooding of the platform, a new subtidal unit is formed and the dissolution stops as fully marine phreatic conditions are re-established.

Decline of trophic conditions and vertebrate bones accumulation in a carbonate ramp environment in the Tortonian-lower Messinian of the Majella Mountain (Central Apennines, Italy)

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Keywords: Carbonate ramp, Lithothamnion Limestone, Trophic condition, Vertebrates, Tortonian-lower Messinia

The Tortonian–lower Messinian of the Majella Mountain is represented by the *Lithothamnion* Limestone Formation, which is the uppermost carbonate unit of the Bolognano Formation. The Majella constitutes the northern extension of the large Apulia Carbonate Platform and preserves an excellent record of the progressive decay of trophic conditions due to the approaching foredeep systems characterized by huge turbidite siliciclastic sedimentation during the early Messinian.

Compositional and sedimentological analyses were used to reconstruct the depositional model and evolution of the environmental conditions. The *Lithothamnion* Limestone's profile is consistent with a homoclinal carbonate ramp, with a wide middle ramp developed in which coralline algae, mainly as nodules, free-living branches, and rhodoliths (e.g. Mäerl facies) dominated the carbonate production. This facies was associated with seagrass meadows that colonises the inner ramp. The outer ramp was characterized by bioturbated hemipelagic marl with planktonic foraminifera and pectinids within the aphotic zone. Three main stages of ramp evolution have been identified. During the first stage, the ramp was subjected to high-energy wave-dominated conditions, suitable for the development of deep rip channels in which accumulations of vertebrate bones have been occurred. In the second stage, the mäerl facies and seagrass meadows developed initially in an oligotrophic setting and then with a slight reduction in light penetration. The third stage involved a general increase of fine terrigenous sediments, associated with a further decrease in light and by the spread of coralline algal bindstone facies. This elevated terrigenous input was associated with increased trophic conditions, as also shown by the occurrence of abundant plankton and LOFAs (low-oxygenated foraminiferal assemblages).

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Dolomitization intensity and paleoclimatic fluctuations: insights from Mesozoic Periadriatic platform carbonates

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Keywords: Mesozoic, Carbonate platforms, Periadriatic, Dolomitization, Early Cretaceous, Monti Lattari.

The multidisciplinary study of the dolomitized bodies in the Mesozoic platform carbonates of the Monti Lattari belt (Southern Apennines, Italy) has shown a broad correlation between different dolomitization styles and climate (Iannace et al. 2011). Near-surface dolomitization in an arid climatic scenario pervasively affected the Norian succession but its significance dramatically decreased during the latest Triassic, as a consequence of major climatic and palaeoceanographic changes which shifted the climate towards more humid condition. During the Cretaceous, a renewal of periodically arid climatic conditions favoured the formation of early dolomite bodies at different stratigraphic heights.

In order to further explore the connection between early dolomites and fluctuating climate conditions, we studied the Early Cretaceous platform carbonates of Mt. Faito (Monti Lattari belt). The studied succession mainly consists of shallow-water lagoonal limestones with frequent dolomite caps. The degree of dolomitization varies along the succession and a 100m thick completely dolomitized interval is present in the upper Hauterivian - lower Barremian.

Field relations, petrography, mineralogy and geochemistry of the analyzed dolomite bodies imply the reflux of penesaline waters (Qing et al. 2001) as the most probable dolomitization mechanism. This near-surface dolomitization process is controlled by physical and chemical parameters reflecting the paleoenvironmental and paleoclimatic conditions during dolomite formation. The degree of dolomitization is probably modulated by changes in accommodation during sea level fluctuations and by the concentration of dolomitizing fluids. In fact, isotope geochemistry suggests that the completely dolomitized upper Hauterivian – lower Barremian interval formed from distinctly saltier brines, seemingly during a persistent arid phase.

When the new data are integrated with sedimentological evidence on the same area for the Aptian and upper Albian (Iannace et al. 2013) and compared with the recently published data on early dolomites of the Adriatic Platform (Read et al. 2016), a robust link emerges between regional climate and dolomitization style. The influence of such a regional scale control on dolomitization may have a significant impact on hydrocarbon exploration in the Periadriatic area.

SESSION S18

New challenges in Petroleum Geology

CONVENERS AND CHAIRPERSONS

Fabrizio Agosta (Università della Basilicata)
Sara Civello (Total E&P Italia)
Francesco Federici (Edison Spa)
Stefano Tavani (Università di Napoli Federico II)
Emanuele Tondi (Università di Camerino)
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Scaling relationships between vein attributes in fault damage zones and fault displacement: example from layered carbonates in the Jabal Qusaybah anticline, North Oman

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Keywords: Fault zones, Fracture pattern, Vein attributes.

Understanding factors that determine fracture patters in fault damage zones is important for predicting fault zone permeability in the subsurface. In this contribution, we present outcrop data on vein attributes collected in 10 strike-slip and 16 extensional fault zones developed in the Cretaceous platform carbonates of the Natih Formation in the Jabal Qusaybah anticline, North Oman. These fault zones accommodated comparable displacements (up to ~100 m) but developed at different burial depths (3-4 km vs 1-2 km). Vein aperture, height (H), and spacing (S) were measured in vertical cross-sections by fault-perpendicular linear scan lines. The damage zone widths of both strike-slip and extensional fault zones increases at the same rate with increasing fault displacement. Statistical analysis indicates that in each fault zone, (1) vein aperture and height generally increase and vein spacing systematically decreases approaching master slip surfaces, (2) deformation intensity, calculated as H/S ratio, tends to increase moving from the wall rock through the damage zone up to the master slip surface, but (3) deformation intensity does not show a robust correlation with fault displacement. This means that fault displacement by itself cannot predict deformation intensity in the studied fault damage zones. We also found that deformation intensity in extensional fault damage zones is generally greater than in strike-slip fault damage zones (mean H/S of 8.2 vs 6.6), most likely due to the greater percentage of veins higher than the bed thickness (22.1% vs 17.9%). Furthermore, deformation intensity in strike-slip fault zones is symmetrical, whereas in extensional fault zones the footwall exhibits a greater deformation intensity than the hanging wall damage zone (mean H/S of 9.4 vs 6.7). The main result is that predictive models of deformation intensity in fault damage zones should incorporate burial stress regime, fault kinematics and number of veins higher than bed thickness in addition to fault displacement.

Geodynamic and tectonic modeling of the basins with unconventional shale reservoirs of Argentina

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Keywords: Geodynamic, tectonic, modeling, unconventional reservoirs, shales, Argentina.

Modeling petroleum systems related to the tectonic evolution of southernmost western Gondwana margin involves an integrated surface and subsurface tectosedimentary study. Extensional and compressional alternating cycles gave place to various basin types and geometries with a resulting notable thickness variations and different burial histories. At a first glance, it is possible to propose that the productive and frontier basins of Argentina are the result of these thermo-mechanical processes acting on the lithosphere with the resulting infilling divided at a high order tectonic controlled depositional sequences (Barredo & Stinco, 2013). Still, in basin and petroleum system modeling it is essential to consider lower order controls like climate and sea or local base level variations if we want to understand the location and evolution of the sedimentary sequences and their related petroleum elements, specially in strong structured areas like the ones of the Andean region. Using geodynamic and tectonosedimentary tools, together with subsurface information it was possible to understand the complex interaction of the supply of sediments, the availability of the accommodation space (both with tectonic components), sea level variations (also with significant tectonic influence) and the climate variations during basin filling which in tern permitted us to model the petroleum systems of the most profitable basins of Argentina. They correspond to Cretaceous, Paleozoic, Cuyana, Neuquén, Golfo San Jorge and Austral that cover 545,000 km2. The corresponding source rocks are eleven (e.g. Yacoraite, Los Monos, Cacheuta, Precuyano, Los Molles, Vaca Muerta, Agrio, Neocomiano, PozoD-129, Serie Tobífera and Palermo Aike formations), all of them with potential to be unconventional reservoirs (Barredo & Stinco, 2013) as more than 500 wells drilled showed a production of 50,000 boe/d. Actually, volume estimations are up to 802 TCF for gas and 27 BBO for oil of technically recoverable resources (Energy Information Administration, 2013). These are marine to lacustrine rocks that comprise ages from Late Devonian to Early Cretaceous. The average TOC are in between 0.5 to 11 (wt%) with variable thicknesses up to 2,000 meters. The aim of the present contribution is to propose a dynamic modeling of the geological processes that occurred in the productive basins of Argentina with unconventional resources.

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The European Shale Gas between perspective and failure

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Keywords: Cost, Market, Price, Production, Reserves, Shale Gas, Unconventional Hydrocarbons.

The high price of oil in recent years has encouraged the development of research in unconventional hydrocarbons. The special geological conditions, morphological and population density have allowed to perfect the techniques (e.g. Hydraulic fracturing) for gas production from argillitic rocks, very compact (Shale Gas), who allowed the US to reach energy self-sufficiency.

Even in Europe researches were initiated in order to evaluate the oil potential of non-conventional hydrocarbons. The results of these analyses have enabled us to highlight the presence of Shale Gas in many European Countries (eg. Poland, Ukraine, UK, France, Austria, Denmark and Germany) and at the same time, they have ruled out the presence in Italy although national law would have forbidden the development.

In recent years, only Poland has launched some research projects for Shale Gas, but the high cost of research and drilling (approximately 4500m deep) and the geological characteristics of these potential reservoir not comparable with those in America, they have excluded the production.

Some research organizations, such as the Energy Information Agency (EIA) estimate reserves in Europe amounting to about 2400 Tcf, although probably only 20% will be recoverable, due to legislative barriers, economic, and population density.

The factor that probably affects more the production of Shale Gas in Europe is represented by high cost of production, not in line with the market price of the European gas and it is difficult to compare the competitive price of the American Gas, which started to be imported in Europe at a very competitive price.

It seems evident that the development of Shale Gas in Europe will depend on the cost of gas in the European market and as long as you have low prices of hydrocarbon charge, it will be difficult to develop them in Europe. In fact, the average price of gas in Europe is now equal to 18c € /Scm, taking into account the different types of supply.

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Hydrocarbon fields and Plate Tectonics: the example of Mesopotamian Petroleum System

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Keywords: Basins, Collisional Tectonic, Evaporite, Giant, Hydrocarbon Fields, Passive Margins, Salt, Source

Many of the giant and super giant hydrocarbon fields are located along actual and past passive margins or in continental areas affected by a rifting geodynamic regime, where huge anoxic basins rich in organic matter were subject to rapid burial. Some of the most significant giant and super giant hydrocarbon fields developed in South America, along the Atlantic passive margin of Brazil, and in West Siberia and Mesopotamian (Iraq and Iran), where old passive margins successively transformed in collisional margins. The most important extensional tectonic phase that affected the Pangea and influenced the passive margins evolution and the formation of anoxic intra-platform basins is connected to the Mesozoic Neo-Tethys and Atlantic opening.

In Mesopotamian area, the main source rocks are Cretaceous in age. The Balambo, Garau and Kazhdumi Formations are characterized by typical basinal sediments very rich in organic matter. In the Persian Gulf, at the base of the local sedimentary succession, that accumulated from the Late Proterozoic to Holocene on the northeastern margin of the Arabian plate, the Infracambrian Hormuz evaporites are present. The Hormuz Complex consists of massive halite, anhydrite, dark limestone and dolomites, red sandstone, shale, and volcanic rocks deposited in complex graben systems formed during the Precambrian extension phase (Najd rifting). As in many others evaporitic passive margins, the geometry of the overlying anoxic basins seems to be influenced by the mobility of underlying evaporite deposits that can favor the formation of a specific framework of horsts and grabens. In the Persian Gulf, as a matter of fact, the major factor that controls the salt uplift is simply the differential rate of sedimentation that affected the whole study basin. Also during the successive compressional tectonic regime that finally caused the collision between the Arabian and Iranian plates the considerable thickness of Hormuz Salts influenced the formation and the preservation of the main traps in Mesopotamian area.

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Geological and numerical modeling to support the production and storage of natural gas

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Keywords: natural gas storage and production, numerical modeling, geological reservoir, GeoSIAM.

The natural gas storage in underground structures known as geological reservoirs plays a key role in the Italian energy system. The gas storage satisfies various needs such as responding to the gas market demands, ensuring wide margins in the management of production facilities and transport nets and ensuring the maintenance of strategic reserves that are used exclusively to deal with exceptional situations.

Studies on natural gas storage are particularly interesting also for the analyses related to the seismicity. In this regard and after the Emilia Romagna earthquake occurred in May 2012, an international commission called ICHESE (*International Commission on Hydrocarbon Exploration and Seismicity in the Emilia Region)* has been established. The conclusions of this commission emphasized the need for further more detailed researches also with the help of numerical simulations (e.g. the studies known as Laboratorio Cavone).

In this context, the present research has been performed with the goal to study, by means of numerical simulations, the industrial process related to the production and storage of natural gas in deep geological reservoirs. More precisely, the methodology developed in order to characterize a gas storage site is shown and its application to a test case located in Lombardia region (Italy) close to the Concessione Sergnano Stoccaggio is discussed.

The methodology pointed out for the site characterization foresees the information collection about the stratigraphy and the lithology of the geological formations, the creation of a static geological model and then the realization of a corresponding 3D fluid dynamic model including the well cluster structures.

In the shown case, the geological reservoir suitable for gas storage is located in the conglomerate formation known as Sergnano Gravel (Lower Oligocene - Upper Messinian) while the caprock is identified in the overlying clay formation known as Santerno Clay (lower Pliocene - Pleistocene). For this area, an accurate 3D numerical model, including geological and spatial discretisation, has been realized using GeoSIAM (GeoModeling Analysis Integrated System, Guandalini & Agate, 2015). At first, the natural equilibrium steady state of the geological reservoir has been searched and verified in comparison with measured data and then a simulation scenario of a typical natural gas production and storage yearly based cycle has been carried out. The obtained results have confirmed the sustainability of the gas extraction and injection process in safety conditions, being the overpressures and underpressures occurring during the cycle always in the allowed range. These results also confirmed the goodness of the methodology based on the GeoSIAM system in terms of accuracy and reliability when applied to the gas field analyses.

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The Application of Fluid Inclusion Studies to the Investigation of Aqueous and Hydrocarbon Fluid Dynamics in Oil Prospective Basins

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Keywords: fluid inclusions, petroleum exploration, oil prospective basins.

The application of fluid inclusion studies to determine pressure, temperature, volume and chemical composition (PVTX) of aqueous and hydrocarbon fluids during the evolution of oil prospective basins is reviewed. Furthermore, we highlight the key roles played by fluid inclusion studies in charting diagenetic and palaeo-oil migration event histories. In sedimentary rocks fluid inclusions contain micron scale samples of aqueous and hydrocarbon fluids trapped in annealed microfractures developed during burial, or earlier in authigenic minerals (*e.g.* quartz and/or calcite), during cementation.

Fluid inclusion microscopy is performed on specially prepared doubly polished fluid inclusion wafers (~150 microns thick). Samples can either be of well core, sidewall core or cuttings. A range of microscopic techniques facilitate the study of aqueous and hydrocarbon-bearing fluid inclusions including: transmitted light microscopy, microthermometry, UV fluorescence microscopy, laser raman microscopy.

Studies by the Geofluids Research Group at NUI Galway, carried out over the last twenty years, of oil prospective basins (offshore Ireland, the North Sea, onshore and offshore Africa, onshore China, onshore South America and offshore Labrador and Newfoundland) are used to highlight the key role played by fluid inclusion microscopy in the oil exploration sector. At its most basic level all of these studies were used to aid the exploration for oil at the micron scale. They also facilitated the development of basin scale models for diagenetic and hydrocarbon fluid dynamics during basin evolution.

The microscopic techniques referred to above provide key parameters that facilitate the estimation of PTVX values which help to constrain the diagenetic history of a basin by providing information on the chemistry of diagenetic fluids. They can also be used to generate isochores (lines of equal density in PT space) using bespoke software to constrain the temperature and pressure conditions of fluid trapping. Consequently aqueous and hydrocarbon fluids within the basin and their chemistry and relative timing of migration of petroleum fluids can be documented. Selected case histories from the studies above will be used to highlight these applications.

In summary therefore, fluid inclusion studies of oil prospective basins have the potential to add significantly to the store of fundamental data on basinal fluids (both aqueous and hydrocarbon) in general, and more specifically on the following parameters:

1. Fluid compositions (hydrocarbon and aqueous fluids).
2. Presence or otherwise of hydrocarbons.
3. Oil charge history (*e.g.* number of oil migrations)
4. Isochore generated pressure-temperature models of aqueous and hydrocarbon fluid trapping.
5. Timing of trapping of hydrocarbon and aqueous fluids in relation to cementation.
6. Inherited oil and aqueous inclusions in detrital grains from sediment source area.

This investigative approach has a key role in de-risking petroleum exploration in sedimentary basins.

Sequence-stratigraphic approach to turbiditic systems through spectral decomposition of seismic data: a case study from offshore Falkland Islands

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Keywords: Turbidites, sequence-stratigraphy, spectral decomposition, RGB blending, seismic, Falkland Island

During Lower Cretaceous times, the Volunteer Sub-Basin, located in the East Falkland Basin, evolved as part of a passive margin (Bry et al., 2004) and was site of turbiditic sedimentation. The use of spectral decomposition on the available 3D seismic dataset helped in shedding light on the depositional history of a sector of this basin. Between Berriasian and Cenomanian, two 2^{nd}-order cycles (*sensu* Vail et al., 1977) have been identified on seismic and the related sequence boundaries tied to the DSDP boreholes on the Maurice Ewing Bank (Barker et al., 1976, MacAulay F., 2015). The different system tracts composing such sequences have been interpreted on 2D and 3D seismic, the latter covering the slope and the basin floor areas. The evolution of this more distal portion of the systems is clearly imaged on the RGB blending volumes generated through the spectral decomposition of the near and far angle stacks. Each sequence is characterised by the activation and de-activation of a series of slope channelised complexes and basinal lobes.

The first events related to an early lowstand, showing narrow incisions on the slope and deposition of mass transport complexes in more distal areas, are followed by a more defined network of channelized systems, which gradually tend, during late lowstands, to become more tortuous and narrower, their filling probably being characterised by finer-grained sediments. Eventually the systems are shut down by a transgressive event. The highstands are represented by thin successions in this distal sector and cannot be easily separated from the transgressive system tract. A structural control on the channel-lobe systems is also evident on the RGB volumes: high-energy systems are usually related to steep slopes, while structural lows are primary sites of channel complexes development on the slope and depocentral areas on the basin floor.

While the RGB blending derived from the spectral decomposition of the near angle stack precisely depicts the geometries of most of these complexes, the far angle stack RGB helps to identify complexes which are not particularly evident on the near angles. Even if the seismic resolution at 4000 to 5500 ms has to be considered relatively low, the spectral decomposition remarkably enhances the imaging of the depositional systems, particularly if compared to traditional seismic and attributes.

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Kinematic evolution of a giant-scale, gravity driven deep-water fold-and thrust belt: the Lamu Basin case history (East Africa)

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Keywords: Deep-Water Fold-and-Thrust Belts, Continental Passive Margins, Balanced Cross-Sections.

The knowledge of modern deep-water fold-and-thrust belts (DWFTBs), widespread at both passive and active continental margins, has been significantly increased in the last decades, due to advances in off-shore seismic imaging. DWFTBs are geological features of considerable economic interest, since many oil and gas fields have been recently discovered in traps associated with these systems.

The Lamu Basin is an example of giant-scale compressional belt developed in Late Cretaceous-Early Tertiary by gravity spreading processes, along the East-African continental margin, at the Kenya-Somalia border. The compressional domain extends longitudinally for more than 450 km, is up to 180 km wide and shows remarkable structural complexity both along strike and along dip.

In this study we present three balanced geological cross-sections across the Lamu Basin DWFTB, based on the interpretation of good quality seismic profiles. A 2D sequential restoration procedure was applied to the layer-cake Cretaceous succession, comprised between the shaly basal detachment and the bottom of the syn-tectonic sequence.

Net shortening exceeds 45 km in the northern wider part of the thrust belt, diminishing to about 15 km toward the south, where the contractional system is decidedly narrower. At the section-scale, average shortening is ≈ 20% (comparable with the maximum values registered in other gravity driven thrust belts), but its along-dip distribution shows a significant variability: higher values are achieved in the outer (i.e. down-dip) portion of the system, dominated by basinward-verging thrust sheets. Both the fold wavelength and the thickness of the detachment shaly unit increase landward, where double-verging structures and symmetric detachment folds accommodate a lower amount of shortening.

As in other similar cases, a linear and systematic relationship between sedimentary thickness and fold wavelength is observed.

Thrusts activity is largely synchronous, with no clear evidence for break-forward or break-backward imbrications sequence. More than 95% of net shortening was produced in less than 10 Myr (during Paleocene) with a maximum shortening rate of 5 mm/yr. After Late Paleocene, minor deformations affected the innermost part of the thrust belt until Early Miocene, indicating a long-lived stage of slow accommodation.

Further research on passive margin, gravity driven DWFTBs is still needed for a full understanding of their mechanical behaviour, comparing these structures with their counterparts, developed in convergent setting, i.e. accretionary wedges and foreland fold-and thrust belts. An effective comparison between modern DWFTBs, mainly explored through seismic surveys, and their fossil analogue, exhumed at the surface, is also still lacking.

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Tectono-stratigraphic seismic interpretation of a 3D seismic volume of the Mississippi Canyon Lease Block 118 (Northern Gulf of Mexico)

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Keywords: Gulf of Mexico, Mississippi Canyon, 3D seismic.

The Gulf of Mexico is one of the most important hydrocarbon provinces and one of the most geologically explored and mining exploited in the world. Geological exploration includes cutting edge seismic surveys, borehole investigations and advance basin analysis study. Because the abundance of high quality 3D seismic data, seismic facies analysis (sensu Mitchum et al., 1977), is one of the most prominent tools for understanding the geological and stratigraphic evolution of Gulf of Mexico subsurface.

This work illustrates an integrated tectono-stratigraphic seismic interpretation of a 3D seismic data volume (25 km^2 wide and 12 sec. deep) collected in the N-E Gulf of Mexico middle slope (Mississippi Canyon Lease block 118). In this area the slope is influenced by salt tectonics, extremely high sedimentation rate from the Mississippi River and sea level variations. The interplay of these processes formed a very complex geology characterized by (1) a western domain consisting of a basinward-dipping normal fault family and associated strata; (2) a central domain composed of a landward-plunging diapiric salt dome, generating a network of crestal faults and two flanking NE-SW trending salt-withdrawal mini-basins. The sequence-stratigraphic architecture of salt-withdrawal mini-basins is further complicated by syn-depositional salt tectonics, which modifies the paleotopography, the accommodation space and the slope depositional processes. A transition from an early sand-dominated Ponded Facies Assemblage to a later shale-dominated, seal and Bypass Facies Assemblage, sensu in Prather et al. (1998), has been clearly recognized occurring at 1 million years ago. Seismic facies succession suggests an eustatically driven mini-basin sedimentation, however salt tectonic still plays a role in sedimentation by driving seafloor topography and episodic mass movements during passive/active diapirism.

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Modes of fault growth and propagation in a multi-reactivated extensional basin: a case study from the Stord Basin (North Sea - Norway)

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Keywords: North Sea, Stord Basin, Seismic interpretation, normal faults, fault reactivation.

Fault bounded structural highs form the principal traps in rift and flexured foreland basins. Commonly in these settings the traps are delimited by a single normal fault but also intersecting bounding structures are frequent. The study of the faults geometry, propagation and horizontal/vertical linkage, coupled with the reconstruction of the syn-sedimentary basin evolution, is crucial to unravel the fluid path migration and trapping (Fossen et al., 2005; Fossen & Rotevatn, 2016); moreover, structural analysis is fundamental in extensional basins affected by multiple and of non-colinear extensional events.

The Stord Basin in the North Sea is a Mesozoic extensional basin interposed between the Viking Graben and the Norway coast. This basin suffered several extensional events occurred during the late-Paleozoic/Triassic, Jurassic and Cretaceous (Færseth, 1996).

A study of a PSTM reprocessed 3D seismic cube extracted from the Seamless dataset by Spectrum has been focused on the reconstruction of the structural evolution of the basin and syn-sedimentary Mesozoic faults.

Fault geometry, trend analysis, throw distribution, and fault parameterization has been performed by GIS sampling tools on data extracted from the seismic interpretation; moreover, several indexes were calculated, including the throw Vs distance (Tx plot), throw vs depth (Tz plots), and expansion index (EI). The results of the analysis indicate the growth of the normal faults occurred both by vertical and horizontal linkage of en-echelon arranged fault segments. The faults are prevalently composed by N-S, NNW-SSE and NW-SE trending segments and their attitude is strongly inherited by ancient basement discontinuities. Analogous fault trends were also observed in the adjacent Utsira High where several oil fields were discovered in fault-bounded structural highs (Bergslien, 2002).

In the study area the faults were affected by multiple reactivations during the Mesozoic extensional events as suggested by the increasing fault linkage maturity with depth. Moreover, the different mechanical properties of the Mesozoic sedimentary multilayer, composed both by sandstones with intervening marls and carbonates, strongly controlled the fault propagation and the vertical linkage between distinct segments at depth.

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The Servizio Geologico d'Italia contribution to the European strategy on GeoEnergy

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Keywords: geological data, geoenergy, georesources, environmental impact, pan-European mapping

Petroleum Geology has been for a long time the engine of the geological research, it allowed to improve the geological knowledge at regional scale and it has provided the main source of energy to support the development of European countries. In the last years, in order to answer the increasing need of healthy and clean living environment, Europe has planned a progressive transition towards a low-carbon energy system. The integration of traditional (oil-based) energy sources with solar, wind, geothermal energy sources, and consequent increasing storage capabilities, points out the need for a publicly accessible common European geological knowledge base.

The GeoEnergy Expert Group of EuroGeoSurveys (EGS), the permanent network of 36 European Geological Survey Organizations, supports the EU policies on geoenergy, georesources and related environmental impacts, with activities and projects aimed: i) to produce database of harmonized and scientifically robust digital information on the subsurface and its potential uses; ii) to develop state-of-the-art methodologies and workflows, focusing especially on consistent cross border and pan-European resource mapping and assessment.

The Servizio Geologico d'Italia – ISPRA, as member of the EGS GeoEnergy Expert Group, participates to EU funded Projects on georesources, among these EUOGA and ESTMAP projects, as a first step to develop an unbiased and agreed pan-European resources assessment, based on independent and public geological information collected and managed by Geological Survey Organizations, and common workflow and evaluation methods.

The EUOGA project (Geological Evaluation of Potential Unconventional Oil and Gas Resources In Europe, H2020 call B.2.9.) main goal is to define a common resource assessment methodology and make results publicly available in a web based GIS database. The Servizio Geologico d'Italia – ISPRA participated to EUOGA project releasing information about the status and development of the shale gas and shale oil in Italy (forbidden by law), collecting public data and relevant shale layer characteristics, and data needed for resource assessment based on critical parameters screening schema.

The main goal of ESTMAP (Energy Storage Mapping and Planning, H2020 call B.2.7) project is to develop a geographical database containing information on existing, future, and potential energy storage sites (sub-surface and above-ground) in Europe. This product will facilitate system modelling, strategic planning and multi-stakeholder decision-making on the EU's future energy system. The Servizio Geologico d'Italia – ISPRA collected and provided public scientific data and metadata on the current geological energy storage situation of Italy, actually consisting of underground natural gas storage and indicating possible future developments.

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The Upper Barremian-Lower Aptian platform to basin system of the Parnassus Mountain (External Hellenides, Greece): Depositional facies model and evolution of a Lower Cretaceous Urgonian-type carbonate platform

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Keywords: Carbonate Platform, Lower Cretaceous, Urgonian, Rudists, Parnassus Mt., External Hellenides.

In this work we present the results of a detailed stratigraphic and sedimentologic study carried out on the Upper Barremian-Lower Aptian Urgonian-type platform to basin system exposed on the Parnassus Mt., which represents the most internal tectonic unit of the External Hellenides. Platform, platform margin and slope to basin successions have been dated and correlated through biostratigraphc analyses based on micro- (calcareous algae and foraminifera) and macro- (rudists) paleontological data.

The late Lower Cretaceous depositional evolution of the Parnassus Platform records the progressive radiation of rudists in carbonate successions. In order to highlight this progressive rudist radiation, the stratigraphic succession has been subdivided in two main units (D1 and D2). The lower unit (D1) is characterized by the development of a depositional system, from the inner platform to the basin. The platform succession is dominated by peritidal cycles and characterized by the development of rudist floastones. Rudists, represented only by caprotinids (*Himeralites*, *Glossomyophorus* and very rare *Agriopleura*), are abundant in the platform succession, but are rather rare in the margin succession (only rare and small *Himeralites*) dominated by microencruster bindstones with dispersed coral framestone. The slope to basin succession is starved of resedimented deposits, which occur only as rare lito-bioclastic breccias intercalated within a succession dominated by fine grained resedimented deposits and pelagic micrites. The upper unit (D2) is characterized only by the development of the platform margin and the slope-to-basin successions. Inner platform facies are lacking due to a widespread emersion of the underlying platform system. The platform margin succession is characterized by the radiation of caprotinids (*Himeralites*), caprinids (*Offneria*) and rare requieniids (*Toucasia*) which form thick and widespread coarse-grained bioclastic geobodies prograding basinward. Slope and basin successions are dominated by pelagic micrites and subordinated fine-to- coarse grained bioclastic deposits.

Our data show that, between the late Barremian and the early Aptian, the Parnassus Platform experienced a significant biotic turnover in the platform margin. This turnover was concomitant with an important emersion of the platform and produced a deep change in the organization of the platform margin facies. A comparison with other carbonate systems of the Tethyan area is made in order to explore to what extent the late Barremian-early Aptian evolution of the Urgonian-type system of the Parnassus Platform represents the response of processes acting at a local or regional scale.

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Time-space evolution of effective porosity in carbonate fault rocks

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Keywords: Fault, Fault core micromechanics, Carbonate fault rock, Porosity, Pore structure.

This work is aimed at deciphering the role played by cataclasis on both amount and distribution of connected porosity in carbonate fault rocks. Despite the great importance of this knowledge for structural geologists dealing with seismic or working in the hydrocarbon, water, and geothermal industries, the micro-mechanics and petrophysics of carbonate fault cores is still matter of debate. In fact, due to paucity of published data, and the profound effects that diagenetic processes such as cementation and pressure solution have on the resulting porosity, a great difficulty arises in the comprehension of the control exerted by grain fracturing and grain rolling on pore type, geometry and connectivity of carbonate fault rocks at shallow crustal levels.

In order to better understand the relationships among micro-mechanisms and porosity, the present work focuses on high-angle normal fault zones crosscutting the Lazio-Abruzzi and Campania-Lucania platform carbonates, Italy. In particular, limestone fault rocks exposed along the Fucino Basin and the Agri Valley, respectively located in central and southern Italy, and dolostone fault rocks cropping out at the Vietri di Potenza relay ramp zone, southern Italy, are investigated by a combined field and laboratory study. In the field, structural analysis is aimed at deciphering the inner architecture of the exposed fault cores, which include a variety of cataclastic rocks and major slip zones. In the laboratory, the representative hand samples collected along individual fault zones are studied by mean of optical microscopy, SEM, X-Ray diffraction and digital image analyses. The goal is to document both composition and texture of the sampled fault rocks, as well as compute the dimensional properties of survivor grains. The results of this multi-disciplinary work are integrated with those arising from petrophysical analysis aimed at deciphering the amount of effective porosity, as well as the pore type, geometry, and dimension of connected pores. Altogether, both structural and petrophysical data are discussed in terms of time-space evolution of effective porosity within individual carbonate fault cores, which may provide useful information to better assess the cross-fault permeability of carbonate fault zones.

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Challenges in the seismic characterization of the sub-salt Cretaceous Offshore Rift Section of the Campos Basin, Offshore Brazil

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Keywords: South Brazil Passive margin, Pre salt exploration, Campos Basin, seismic intepretation.

The Early Cretaceous (Berriasian to Aptian) rift section of the Brazilian basins represents the sedimentary record that is associated with the first stages of Gondwana break-up. This section records elements of the most important petroleum system of the basins on Brazil's eastern margin (Mohriak et al, 2008). In the Campos Basin this interval is the main constituent of the petroleum system, containing the main source rock and important reservoirs. However of the rift interval still little is known in stratigraphic and seismic facies terms, due to the challenging condition of drilling and seismic imaging of the pre salt rift structures. Reservoirs in this domain are in fact complex, heterogeneous, with layered carbonates apparently poorly connected which makes accurate reservoir characterization very difficult. By using the massive existing 2D seismic dataset and two deep well logs and core information, recently a new tectonostratigraphic evolution of the area has been proposed (Ene et al. 2015). The combined use of image processing techniques with well log analysis has improved the characterization of some mains facies associated to some sub units of the Lagoa Feia (Ene, et al.,2015; Alvarenga et al., 2016). This represented an introductory step to a facies classification applicable at regional level in the SE Brazil offshore area but the seismic expression of the pre salt units is still very difficult and the resolution of the current seismic stratigraphic analysis need further fine tuning to de - risk the recognized petroleum prospects in that area. Our study here deals with the challenges and uncertainty related to the seismic characterization and imaging of the stratigraphy of the lacustrine section from the Lagoa Feia Group in the Campos Basin. Some suggestions to tackle future pre salt seismic imaging and interpretative challenging issues are also proposed.ù

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Internal architecture and processes associated with mass-transport deposits in basinal carbonates, Southern Italy

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Keywords: Mass-transport deposits, Basinal carbonates, Gargano Region, Maiolica Fm.

In this study, we describe intraformational mass-transport deposits (MTDs) at various scales occurring within base-of-slope to basin sediments of the Maiolica Formation exposed in the Gargano Promontory, Southeast Italy.

As MTDs represent important mechanical and sedimentologic heterogeneities in the sedimentary successions, their sedimentological and structural characterization is crucial to better understand and quantify the role they play on both lateral and vertical fluid flow. Several outcrop studies on internal architecture and spatial distribution of MTDs have been made in the siliciclastic rocks, however only few have dealt with gravitational processes in basinal tight carbonates.

A structural analysis was carried out in order to describe extent, spatial distribution and internal architecture of the MTDs of various scale. The internal architecture of medium- and small-scale MTDs showed various stages of lithification of the failed material. Moreover, the medium-scale MTDs have often a bipartite character, as they are composed of horizons of debris and coherent slumped beds. The large-scale MTDs exhibit many structural features (faults, thrusts, folds, erosional surfaces and extensional sedimentary dykes) similar to those of tectonic origin. The origin of these features may be confused, as only few key outcrops are large enough to provide the evidence of MTDs presence. In addition, large mass movements often cause distortion of the strata bellow (basal shear horizons). These deformed strata may appear like simple small-scale MTDs however they show different structural characteristics.

Based on field observations, a model for both meso-scale and large-scale gravitational events along the paleoslope of the carbonate platform was proposed. This study may help to understand the emplacement processes of the MTDs within the basinal environment and may help to decrease the uncertainty of the reservoir characteristics within naturally fractured basinal carbonates.

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Large extensional fissure fills within basinal carbonates, Southern Italy

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Keywords: Extension, Fissures, Basinal carbonates, Maiolica Fm.

This paper deals with large, vertically-developed breccia bodies occurring within basinal sediments of the Maiolica Formation cropping out in the Gargano Promontory, Southeast Italy. Aforementioned breccia bodies cut vertically the stratigraphic succession and both the lithology and the mechanical properties of the breccia bodies vary significantly with respect to the surrounding succession (thin-layered tight carbonates with intercalations of MTDs). The origin of these structures has not been addressed before.

Similar features have been described in outcrop studies of carbonate successions as neptunian dikes (Wall & Jenkyns, 2001; Playford et al., 2009) or in the siliciclastics as sand injections (Hiscot, 1979, Wheatley et al.,2016) however the dimensions of these analogous features were of smaller size.

A structural analysis was performed to describe their orientation, dimensions and filling. Very often their dimensions exceed the outcrop scale. The large breccia bodies are characterized by haphazardly organized clasts of various sizes. Their distinctive features (vertical and parallel walls with infilled fissures, dome-shape capping, their chaotic filling, no evidence of paleokarstic processes and association with faults) may lead to conclusion that these breccia bodies are linked to extension. We propose several possible scenarios of the formation of these vertically-developed structures based on the observations.

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Hydrothermal dolomites in carbonate-dominated rifts: spatial and temporal distribution, petrophysical properties and fracture intensity (Hammam Faraun Fault Block, Suez Rift, Egypt)

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Keywords: Carbonate-Dominated Rifts, Hydrothermal Stratabound and Massive Dolomites, Petrophysical Properties.

Fault and fracture networks exert an important control on fluid flow and distribution of diagenetically altered bodies such as dolomites (Davies G.R. & Smith L.B., 2006, Hirani J., 2014), which due to their dissimilar mechanical properties with respect to limestone are characterized by different fracture intensity (Laubach S.E. et al., 2010).

This study focuses on selectively dolomitized Eocene limestones in the footwall of Hammam Faraoun Fault, a major 5 km displacement block bounding fault in the Suez Rift (Egypt). The studied Lower Thebes Fm. is mostly composed of slope packstone and remobilized carbonate bodies represented by matrix-supported conglomerate and grainstone. Dolomitization in the study area occurred in two main phases and resulted in facies-selective stratabound dolomites extending discontinuously for up to 2.5 km from the fault plane and massive dolomites in the vicinity of the fault plane. Based on isotope analysis the first phase of dolomitization occurred during the rift initiation whereas the second phase formed during the rift climax stage (Hirani J., 2014).

Petrographic and petrophysical data from different limestone lithofacies and their dolomitized equivalents have been analyzed in order to link the fracture distribution with the mechanical properties of the studied rocks. Stratabound dolomites are characterized by lower porosity and smaller pore size than massive dolomites whose porosity is more similar to the one of limestone. Overall, dolomitization leads to an increased number of fractures with respect to limestone. However, massive dolomites do not enhance the number of fractures significantly and the precursor limestone lithologies seem to be more important parameter controlling fracture frequency in these dolomites.

The results of this work improve our knowledge about the fracture distribution within hydrothermal dolomites in rift systems and the impact of dolomitization on the mechanical properties of the reservoir rock. As such, it can help to improve prediction of fluid flow and porosity-permeability distribution in limestone-dolomite reservoirs.

This work was supported by Department of Earth Science (University of Bergen), Hammam Faraun Dolomites project (HFF-DOL) and VISTA postdoctoral project of Korneva I. "Interaction of structure, sedimentary architecture and mechanical stratigraphy in the diagenetic alteration of rift-related carbonates".

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Background and Fault-Related Fracture Networks in the Mesozoic Carbonates of Monte Alpi, Basilicata, Italy

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Keywords: Fractured carbonates, Background deformation, Fault related deformation, Apulian platform.

The Monte Alpi is a key area to decipher the geometry and distribution of the fracture network dissecting the Mesozoic carbonates pertaining to the inner Apulian Platform. In fact, a thick limestone succession of Jurassic-Cretaceous ages topped by a mixed carbonate-terrigenous cover of Messinian age is nicely exposed along the cliffs of Monte Alpi. There, high-angle faults characterized by a polyphasic kinematics activity crosscut the whole Mesozoic-Cenozoic succession. In particular, both strike- and dip-slip extensional components of faults polyphasic activity are recorded along the main slip surfaces of the high-angle faults striking about N-S and NW-SE, whereas only dip-slip extensional kinematics are recorded along the NE-SW fault planes.

This study is aimed at deciphering the attitude and dimensional properties of both background and fault-related fractures that crosscut the Mesozoic limestones. A detailed field analysis of outcrops exposing pristine and faulted limestone beds, and subsequent data elaboration and bedding restoration, allow us to recognize a background fracture network made up of two sets of bed-perpendicular, cross orthogonal joints. Such a network includes joints striking about N-S and E-W, with E-W joint sets being generally confined between the more persistent N-S joint sets. In some cases, the abutting relationships shown by the two aforementioned joint sets are consistent with their formation due to the stress-state transition mechanism, which took place under vertical loading during burial diagenesis.

The fracture network associated with faulting is made up of high-angle joints and sheared joints striking N-S, NW-SE and WNW-ESE respectively. Based upon the fault kinematics deciphered from the high-angle fault network, we related the NW-SE and the WNW-ESE oriented joints to both strike-slip (first) and normal (later) fault activity; whereas, the N-S and the NE-SW oriented joints are related only to the normal fault activity. A multi-scale best fit law for spacing and the coefficient of variation were computed for each joint set. The results show that the spacing increases proportionally with the bed thickness for the N-S and E-W joint sets (background network). Whereas, the NNW-SSE, NW-SE and WNW-ESE joint sets (fault-related fracture network) do not show any spacing correlation with respect to the bed thickness. Ongoing field analyses of new outcrops exposing the fracture network pertaining to individual fault zone will shed new light.

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The External Thrust System in Western Sicily

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Keywords: Sicily, External Thrust System.

Already since 1990 Carbone & Lentini (1990) had highlighted the existence in Basilicata of a deep seated thrust system buried beneath the Apenninic nappes. First they named it "Apulian Chain" and later, once defined the structural features, "Apulian Thrust System" (Lentini et al., 1990).

The similarities with the Sicilian orogen led the authors to address the research on this "External Thrust System", totally buried in eastern Sicily, but outcropping extensively in the western sector of the island (Pelagian-Sicilian Thrust Belt). That has led the authors to hypothesize a Sicilian petroleum target, as it turned out in the southern Apennines (Lentini et al., 1996).

While in Val d'Agri the Apulian Thrust System is mostly buried (with the exception of the Monte Alpi) and can be detected through subsurface investigations, in western Sicily and in particular the areas of Trapani, the excellent exhibitions allow to study geometries and structural characters of the External Thrust System.

In Monte S. Giuliano (Erice) and along the San Vito Lo Capo Peninsula crops out a thrust system, consisting of Triassic-Liassic carbonate platforms with Jurassic-Cretaceous basinal horizons. The first siliciclastic deposits can be attributed to the Middle-Late Miocene. This system, complicate in detail, shows a southward vergence with various back-thrust and has been originated during the Late Pliocene up to Quaternary, as evidenced by the full involvement of Trubi Fm. The young age of the terrigenous cover and the regional dextral NW-SE oriented fault system, based on the field work integrated with the interpretation of seismic lines, allows to ascribe these units to an external domain, the Pelagian Sicilian Thrust Belt (Lentini & Carbone, 2014) and are not attributable to the Panormide units, as stated often in geological literature.

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Densely spaced historic drilling data & modern 3D reservoir modelling of a carbonate oil field (Maiella Mountain, Central Italy); heavy oil distribution and its controlling factors

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Keywords: Carbonate Reservoir Analogue, Heavy oils field, 3D Reservoir Modelling, Maiella, Petrel.

Heavy oil and bitumen have been extensively exploited in Italy in the past centuries. In years 1935-42, in particular, there has been an intense effort to produce national hydrocarbons: this resulted in the creation of a company called ALBA («Azienda Lavorazione Bitumi Asfalti»), which aim was to assess Bitumen/Asphalts resources from the known outcrops along the Italian Peninsula.

In the Abruzzo region, investigations were concentrated over the Maiella NW flank, where carbonate reservoirs from Upper Cretaceous (Orfento and Santo Spirito fms), to Miocene (Bolognano Fm), are locally filled with hydrocarbons. ALBA's exploration activities resulted in the drilling of about 180 shallow vertical wells, regularly spaced over grids of 100x100m/200x200m, with depths in the range of 80-250m.

During our research we found reports and documents from these geological investigations (c/o Eni historical archive in Pomezia), that we integrated with field observation, laboratory measurements and thin section analysis.

All the data were then combined to build integrated 3D reservoir models (Petreltm) of these partially outcropping heavy oil fields, reconstructing HCs lateral and vertical distribution within the reservoirs, modelling key petrophysical/acoustic parameters and calculating HCs volumes.

The dense well pattern, mainly over the lower Bolognano reservoir interval (Bryozoan & Lepidocyclina lmst), together with field observation, allow making some observation.

There are no evident preserved structural/stratigraphic traps easily justifying the observed distribution of HCs, and this does not appear directly controlled by fault pattern today recognised at surface.

HCs are mainly associated to primary porosity reservoirs with only limited secondary fracture porosity: secondary faulting/fracturing appear only as local poro-perm enhancement narrow belts cutting across reservoirs.

In the modelled areas, HCs distribution within the reservoir interval appear to show some SE-NW oriented polarity, which can be tentatively correlated with the known depositional geometries associated to the Oligo-Miocene carbonate ramp development.

In general, HCs distribution over the area suggest that HC migration was likely taking place before and during the growing of the Majella structure, until the whole system was exposed during the last exhumation phase: HC pools, possibly associated to local structural traps, were then likely frozen in a non-equilibrium state and oils were reduced to bitumen: the biodegraded oils lost their mobility also acting as lateral seals and creating complex traps; moreover, active aquifers could have acted as controlling factor, by hydrodynamic stagnation.

Data also suggest a migration model in which dynamic parameters, such as relative permeability and the change of fluids characteristics with time, during the exhumation process, could have played a major role.

Seismic characterization of fluid escape pipes from the Loyal Field (Scotland, UK) using high resolution 4D seismic surveys

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Keywords: 4D seismic interpretation, Loyal Field, fluid escape pipes.

Pore fluid expulsion may occur as sand intrusions, mud volcanoes and highly localized fluid escape pipes. Their expression has been accumulating for the past two decades due to the improved seismic data quality. However, resolution problems bring considerable uncertainty in their correct characterization, with many potential artefacts contributing to the seismic appearance of fluid escape pipes (Cartwright & Santamarina, 2015). The strong uncertainty in defining their internal structure has also triggered discussions about hypothetical mechanisms for their genesis and association with cyclically overpressured root zones. The mechanisms proposed so far, span from hydraulic fracturing, erosive fluidization, capillary invasion and any of their combination. With the aim of contributing to the understanding of the fluid escape-genesis we present and discuss a 3D detailed mapping analysis of the full and partial stack surveys (processed using amplitude preservation techniques) imaging a series of fluid escape and pore fluid expulsion affecting the overburden of the Loyal field (West Shetland, 204/205 quadrants of the UKCS). The analysis revealed for most of the fluid escape pipe, a deep root zone sited beneath the Top Lista Formation (corresponding to the T35 BP unit and acting as seal) and propagating across the post Paleocene units through conduits structures of variable geometry. Many pipes appear to terminate in correspondence of an erosive unconformity, tentatively identified as the Intra Neogene Unconformity (INU of Stoker et al., 2002), thus constituting an upper temporal boundary for the pipe formation, which are interpreted to be relict nowadays. A 3D geometrical and quantitative characterization of the different pipes is also presented. The mapping shows that pipe got length range of 600-1000 metres (up to 1600) and diameters from a few tens up to several hundreds of metres. The conduits geometry is quite variable, but in several case they show an abrupt upward deflection of seismic horizons not consistent with simple artefact due to the gas leakage. That, is interpreted as the seismic response of mixed hydrocarbon and mud upward propagation. Further amplitude analysis using the partial stacks data revealed a multi stage intrusive mechanism, alternating period of initial rapid overpressure to lateral slow 'flow' pore fluid migration. Finally, some pipe alignments suggest the presence of fault controlled pathway but the largest pipes are clearly unrelated to visible faults (by crossing it) accounting for a structure-independent propagation.

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Inferring geometry and distribution of lamination-controlled fractures in microbialites

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Keywords: Fractured reservoirs, microbialites, Monte Carlo modelling

In this work we present results on the influence of microbialites deposition environments on fracture geometry and distribution. Fracture propagation across bedding is often prevented by the strong anisotropy produced by layering. On the other hand, lamination introduces a weaker anisotropy that deviates the average fracture propagation forming fractures with a characteristic staircase geometry. On a section normal to the sedimentary layering/fracture intersection, this geometry consists of stepping fracture segments running parallel to the lamination/layering (LaP) connected by ramp segments cutting across the laminations.

The architecture of staircase fractures can be parameterized by the L/R ratio (the ratio between the lengths of the LaP and ramp segments) and the cut-off angle (the angle between the ramp segment of the fracture and the lamination), in turn depending from the stress regime.

From the mechanical point of view, Ramp and LaP segments are produced by two different mechanisms. Ramp segments initially form as shear fractures in dynamic stress conditions (i.e. failure stress conditions) and later evolve as extensional fractures after the development of LaP segments. These form as kinematic shear fractures (i.e. related to relative blocks sliding) in order to accommodate the overall extensional fracture opening. The sharp intersection observed between LaP and Ramp segments confirms that there is no stress rotation at their intersection suggesting a stress partitioning into a prevailing tensile component along the ramp segments and a prevailing shear component along LaP ones.

A physical model of staircase fractures has been developed considering the effect of the rheological contrast between the layer and the intra-layer infilling, the fluid overpressure and the overburden.

The model has been successfully applied to laminated rock outcrops. The rheological parameters needed to match the observed geometry were obtained using a Monte Carlo approach. The obtained rheological parameters are comparable with those presented in the literature and justify the LaP/Ramp proposed model. Two distinct behaviors were found and quantified depending on the original angle between stress regime and lamination/layers. These two behaviors are labelled flat zones and slope zones fracturing and are related to the depositional environment energy parametrized by the average lamination dips (<30° and >30°, respectively).

Fluid pressure plays an important role in the development of the LaP segments by reducing the effective stress.

The presence of LaP segments strongly influences the fracture induced permeability in these rocks by increasing connectivity between fractures of the same system thus strongly improving the secondary permeability due to a single fracture system.

Results have been successfully applied to model fracture-induced permeability in microbial oil reservoirs in the Southern Atlantic.

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Synthetic seismic modelling of a base-of-slope carbonate system of the Maiella Mt. (Central Italy): new insights for constraining reservoir geometries from outcrop analogues

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Keywords: Seismic modelling, Maiella Mo untain, Outcrop analogue.

This study shows the importance of incorporating studies on outcrop analogues in the analysis of geobodies representing potential reservoirs. Within this context, the 2D and 3D geological and forward seismic modelling have been realized to explore the seismic response of an exposed escarpment-bounded platform and their related sedimentary products. In such a kind of carbonate systems, the platform escarpment and related breccia deposits represent two main sedimentary features particularly relevant in the subsurface for trapping hydrocarbons. Base-of-slope breccias and megabreccias, which represent potential reservoirs, may show different temporal and spatial distribution, variable dimensions and lateral extent; they may pinch-out within base-of-slope sediments or onlap towards the platform escarpment. These features are important for building a well-constrained geological model and have to be taken into account when interpreting subsurface geophysical data during the exploration phase. Thus, the computation of a synthetic seismic model built from outcrop data provides a valuable tool for better understanding the seismic response of subsurface carbonate sedimentary features.

After the 2D and 3D geological modelling construction, the seismic modelling has been carried out with ray-based modelling methods. Poststack time-domain migrated synthetic seismic sections were first generated from the impedance models by standard ray tracing. Different dominant frequencies for the source wavelet were applied in the model illustrating the effect of different seismic resolutions. For more advanced modelling, taking into account 2D illumination and resolution issues, a Prestack Depth Migration simulator was used to simulate PSDM sections (Lecomte et al., 2016). Finally the same synthetic PSDM simulator was applied to obtain 3D cubes generated from the 3D Vp,Vs and Rho model, showing the seismic response of the paleoescarpment and megrabreccia bodies, revealing, e.g., which is the most appropriate dominant frequency for visualizing the seal and the geometries of the megabreccias bodies as target reservoir (Mascolo et al., 2015).

2D and 3D forward seismic models of the Maiella outcrop represent powerful tools for investigating the seismic expression of complex geometric features given by carbonate base-of-slope systems. Moreover, this study provides a solid base for further investigations aiming to define internal parameters and heterogeneities of potential reservoirs represented by base-of-slope breccias.

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The role of geoscientists in the new world of energy

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Keywords: geoscience, energy, E&P industry.

The geoscientists know the earth and its history. We know that the earth is continuously changing, as the solar system and more generally the universe. For more than a century, the geoscientists are working with the industry, the HC E&P, the mines, the water supply among others. The main drive of this fruitful collaboration, for the academic point of view, was the access to the subsurface data. Major improvements in geosciences have been achieved thanks to the 2D then 3D seismic acquisition. Subsurface imaging have change our understanding of the deformation mode in the sedimentary rock. The visualization of the sedimentary bodies in 3D thank to the seismic and to the logging has completely changed our knowledge of the sedimentary process. In parallel the need of the oil and gas companies to derisk the wells have allowed the researchers to develop powerful 3D tools to test our hypothesis and to extract knowledge from the recorded signal. However, the oil and gas industry is not the only branch which needs geoscientists. In the new mix energetic, the energy is also mainly coming from the earth and from the solar system: all the EnR production required geoscientists. Geothermy consists on producing hot water from often tight reservoir and urgently need improvement on seismic imagining on volcanic domain and logging at high temperatures. Fractures, natural as induced, fractures infilling and fluid rock interaction are key issues. Wind industry, especially offshore, marine current power are using similar techniques that the oil industry, a better knowledge of sea bottom stability around our costs is necessary. Storage is a major issue as soon as the ratio of intermittent energy is large in the mixt. Hydrogen may be an alternative and underground heat storage also. Biogas is done with immature organic matter and the CO2 created by this combustion is stored on olivine beds exactly as the big volcanic traps have stored the CO2 after the massive volcanic period. Researchers are now exploring how to do biofuel and biogas from the algae, all the ones working with the oil and gas industry know that nature is doing that from almost 1 byr. Just mimicking it, is may be the solution.

The geoscientists are not always understood in the industry or by the decision makers. Even in the E&P industry or in the mines there are still managers to consider that we are not very useful. In the large debate about the climate, globally, we have been unable to explain that the ten of years is not the right time scale to study the CO2 cycle. You may consider or not that the new mix is a good news, whatever your opinion it is a fact. As citizen we have responsibility to don't stay isolated and to put our knowledge's at the service of a better "use" of the earth richness and/or to alert when there is a risk. As researchers, we need data to progress, all the challenges that colleagues and companies working in these renewable energies face will result in new data acquisition, new way to explore the questions. It'll surely help to solve major "theoretical" issues that we didn't understand yet.

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Heterogeneities in carbonate settings across scales

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Keywords: carbonate reservoirs, petroleum reserves.

Carbonate reservoirs represent a large amount of worldwide petroleum reserves, including emerging unconventional resources. Carbonate settings are characterized by extreme variabilities in properties (e.g., porosity, permeability), which are difficult to predict in subsurface settings. In carbonate settings, the complexity derives from variability in depositional environments in space and time, diagenetic processes and consequent changes in the pore systems. Furthermore, fractures and tectonic deformation are superimposed on the sedimentological properties.

Quantitative field studies offer a new approach to link surface and subsurface data and to identify key processes generating heterogeneity at different scales. Field data provide an advanced understanding for the different processes relevant for the different scales and their interaction In fact, field studies provide the key to identify the best modeling approach to predict carbonate property distribution in the subsurface. A variety of case studies will be discussed to highlight how different scale of data require different concepts and approaches to best predict heterogeneity in carbonate settings.

Structural architecture and Discrete Fracture Network modelling of sheared Neptunian dikes in tight carbonates, a case study from western Sicily.

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Keywords: Neptunian dikes, structural architecture, Discrete Fracture Network, NW Sicily.

Neptunian dikes are open fissures, which form at the bottom of submerged basins, infilled with sediments younger than the host rock. Neptunian dikes are widespread throughout the Mesozoic carbonate platforms that developed along the northern continental African margin. Currently, these structural features are nicely exposed along the western portion of the Sicilian belt. In particular, Neptunian dikes are documented within Trias-Lias carbonate successions cropping out at the Kumeta Mt., Rocca Busambra, Maranfusa Mt., Magaggiaro Mt., and Montagna Grande sites. Aiming at understanding the role exerted by Neptunian dikes on the fluid flow properties of carbonate platforms, this work focuses on sheared Neptunian dikes exposed at Maranfusa Mt. Since the Lower-Middle Jurassic the northern margin of the African plate suffered extensional deformation leading to the formation or reactivation of syn-sedimentary normal faults and Neptunian dikes. By means of both field and laboratory analyses, two main sets of sheared Neptunian dikes striking NW-SE and NE-SE are investigated. The first set of Neptunian dikes shows an infill made up of pelagic limestones, pelagic micrites with crinoids, micritic marly limestones with planktonic foraminifera, and cataclastic breccias. They show an oblique transtensional kinematic acting until the Upper Valanginian-Albian. On the contrary, the second set of Neptunian dikes is characterized by a more homogenous infill, which consists of pelagic marly limestones with foraminifera and cataclastic breccias. This set is characterized by a rigth-lateral trascurrent motion acting during the Upper Cretaceous-Eocene time. On the basis of the structural architectures assessed for background deformation and for the damage zones of two NW-SE striking Neptunian dikes, Discrete Fractures Network models were built at tens of me-scales. The FRED edition of FRACMAN^{TM} (Golder Associates Group) was employed to build up 10–long, 20 m-wide and 10 m-thick geo-cellular volumes that includes 10 cm x 10 cm x 10 cm cells. For individual fracture sets the following data were inputted: (i) fracture orientation; (ii) volumetric fracture intensity (P32); (iii) fracture dimension (equivalent radius and aspect ratio); (iv) fracture aperture (mechanical aperture for porosity computations, hydraulic aperture for permeability computation); (v) probability of fracture termination. The goal is to decipher the fluid storage and migration properties of the sheared Neptunian dikes, in order to assess the role played by shear-related fractures and subsidiary slip surfaces on the fault-parallel and cross-fault fluid flow and containment properties.

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Microstructural and petrophysical analyses of fractured platform limestones, Altamura Formation, Italy

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Keywords: Tight limestone, fracture porosity, DFN, ultrasonic velocities, matrix porosity.

This work aims to understand the role of matrix and fracture porosity on the fluid flow properties in tight carbonate rock reservoirs. We use 3D exposures of Upper Cretaceous limestones in the Murge Plateau, Southern Italy, to conduct field and laboratory analyses on a good surface analogue of the hydrocarbon reservoirs exploited in the region.

The carbonate succession is characterized by decimeter thick sub-horizontal and laterally continuous limestone beds that represent meso-scale peritidal cycles. The limestone is affected by a fracture stratigraphy and, in particular, the fracture distribution is controlled by three hierarchies of mechanical interfaces: i) bed surfaces, ii) prominent subaerial exposure surfaces, and iii) sedimentary breccia horizons. These interfaces form boundaries between single beds, bed packages and bed package associations, respectively, in which stratabound and non stratabound fractures as well as small faults develop. Field analysis and Discrete Fracture Network modelling undertaken at different scales allow us to determine the control exerted by individual fracture sets on both fracture porosity and permeability.

Integrated petrophysical and micro-structural analyses were performed to qualify and quantify the fracture and matrix porosities. Matrix porosity (ϕ) within individual beds ranges between about 1% and 4%. The maximum values correspond to the bottom of individual beds, likely due to higher abundance of vuggy/moldic pores localized quite selectively on former fossils sparse in the carbonate matrix. Ultrasonic measurements show a small increase in P-wave velocity (V_p) with increasing confining pressure, indicating that the limestone has a stiff pore structure (pores sub-spherical in shape). The V_p-ϕ relationship and microstructural analyses further suggest that the majority of the porosity is due to non-selective dissolution (vug porosity). Microfractures do not contribute significantly to the whole porosity and, according to V_p measurements, do not produce any microstructural anisotropy.

Results, discussed in terms of fluid storage and migration properties of the study fractured tight limestone rock, show that the matrix porosity plays a more significant role in the storage capability than the fracture porosity. However, at meso-scale, are the main (i.e. fractures, faults) structural elements affecting the carbonate multi-layer that form the principal fluid conduits, enhancing fault-parallel fluid flow.

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DFN modelling of a hydrocarbon-bearing, oblique-slip, extensional fault zone exposed along the northern flank of the Maiella Mt., Abruzzo, Italy

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Keywords: DFN modelling, fracture porosity, correspondent permeability, fault damage zone, fault-related el

This work presents the results of DFN modelling of a carbonate fault damage zone exposed along the walls and pavements of the Roman Valley Quarry, which is located along the northern flank of the Majella Mt. According to the proposed conceptual model of fault evolution, different scenarios of fault-related structural elements are modelled in order to assess the control exerted by fault zones with a various degree of maturity. In particular, the relative control exerted by diffuse deformation (background elements) and localized deformation (fault-related elements) on the computed values of fracture porosity and correspondent permeability is assessed.

The study oblique-slip extensional fault zone solved about 100 m-offset. It formed during Middle Pleistocene after folding by flexural slip and thrusting deformation. The study fault zones was previously investigated in terms of faulting mechanisms, fault growth and resulting fault architecture, as well as to decipher the scalar and dimensional properties of individual structural elements. At first, a $1m^3$ Background Model is built by considering the three main sets of pressure solution seams related to the early thrusting and folding deformation stage. Then, four different DFN models are built in a 500 m^3 geo-cellular volume. The Up-sized Background Model includes all background structural elements. The Incipient Fault Model comprises background structural elements and those associated to the initial and intermediate stages of faulting. The Small Faults Model takes into account the through-going slip surfaces, which are more persistent structural elements compared to the previous ones, cutting across multiple carbonate beds but confined within individual carbonate units. Finally, the Medium Faults Model also includes a 10 m-long fault that cut across the whole geo-cellular volume, and represents a portrait of the investigated 500 m^3 portion of the carbonate fault damage zone.

The overall results of this work are consistent with the subsidiary faults forming the main repository for underground geofluids. In fact, these structural elements profoundly impact the computed values of fracture porosity. Differently, the fluid migration paths are mainly enhanced by opening-mode-related fractures, which localize at the extensional quadrants of sheared pre-existing elements and through-going slip surfaces, determining the pronounced fracture anisotropy of the carbonate fault damage zone.

Study of micro- and nanopores in tight carbonates (Zechstein 2, Southern Permian Basin, NW Europe)

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Keywords: micropore, nanopore, diagenesis, tight facies, carbonate rocks, Late Permian, Zechstein, NW Europe.

The study evaluates pore systems in samples of tight Upper Permian Zechstein 2 Carbonate (Z2C) facies from widely dispersed locations in the eastern and western parts of the Southern Permian Basin, NW Europe. Samples of Z2C drill cores comprising platform to shallow-basin deposits were examined by petrographic techniques, porosity measurement and SEM analysis, in order to develop a better understanding of porosity development and pore microstructure. Four carbonate lithofacies were identified by core-scale and thin-section analyses: subtidal/intertidal planar stromatolites and thrombolites; slope facies (laminated dolo- and lime-mudstones and grain-dominated turbidites); toe-of-slope/lower slope facies (laminated lime mudstones with turbidite beds); and shallow-basin (embayment) facies (laminated lime mudstones and hemipelagic deposits). Porosity ranges from 0.08% to 9.6% and is lowest in the subtidal/intertidal planar and columnar stromatolites. The highest porosities, in the slope and shallow-basin (embayment) lithofacies, probably resulted from catagenetic processes and microbial activity. High porosity in subtidal thrombolites is related to the original pore network. SEM analyses showed that pores are present within organic matter, pyrite framboids and microfossils, and between crystals. Subtidal/intertidal planar and columnar stromatolites and thrombolites have a high proportion of nanopores, probably resulting from microbial activity. Although porosity development is a combined function of the presence of organic matter and mineral components, together with sediment fabric and fractures, it is mostly a result of the early diagenetic transformation of mineral phases, microbial activity, and evaporite and carbonate dissolution.

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Microbial mats and microbialites: mineral precipitates and source-rock potential (Mesaieed Sabkha, Qatar)

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Keywords: microbial mats, carbonates, lipid biomarkers, early diagenesis, Qatar.

Much research in recent years has focused on the role of microbes and their associated EPS (mucilage) in the precipitation of carbonate. In modern high-intertidal-lagoonal microbial mats from Qatar in addition to dolomite, aragonite and calcite, Mg-silicates are also identified. The mats reach >5 cm thickness over a carbonate mud substrate, rich in seagrass, gastropods and other small bioclasts. A clear lamination, with distinct downward colour changes from green to pink to brown, reflects different microbial mat communities, from cyanobacteria to archaea including possible viruses. The initial precipitates within the top mm of the mat are composed of amorphous Ca-Mg-Si-C-O. Within a few mm, Mg-Si crystallites take the form of a felted mass of palygorskite-type fibres associated with HMg-calcite and dolomite as micron-sized crystals. Aragonite peloids (tens of microns in size) are locally abundant, these are composed of sub-micron nanocrystals forming fanning bundle crystallites that often mineralize EPS and bacterial bodies. Pyrite nanocrystals and framboids are presents in the deeper layers of the mat. Porewaters are saturated for dolomite, much less so for calcite and aragonite, and undersaturated for gypsum. The source of silica for the Mg-silicates is likely to be windblown dust, which in the region is composed of 33% SiO2, with high levels of Ca and Mg too. Mg2+ is likely 'mopped up' by the EPS and Mg silicate precipitation driven by pH changes within the mat, induced by microbial activities. With TOCs in the region of 10%, organic geochemical analyses show the increasing development of n-alkanes with depth in the mat and the presence of squalene and diploptene derived from archaea and cyanobacteria respectively. Biomarkers also indicate a contribution from higher plants (likely grass and mangrove debris) to the TOC. Microbial mats clearly have a high potential to become source rocks as long as they can be preserved with their early-formed hydrocarbons. Preservation depends on early lithification, hence the importance of mineral precipitates within the mat, and the subsequent depositional history. Scenarios favouring preservation of the hydrocarbon-generating mats include sabkha progradation and rapidly transgressing lagoonal lime muds. The latter may also be organic rich and so contribute to the overall source rock potential.

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Deep-water sandstones in tectonically complex systems: the Numidian of Sicily as an example

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Keywords: Numidian system, confined turbidites, active basin, facies variations.

The turbidite systems of the central Mediterranean-Alpine region are widely used as analogues for a variety of deep-water hydrocarbons reservoirs. Understanding whether the system is unconfined and deposited on relatively unstructured basin floor or confined by actively deforming basin-floor is important for the prediction of sand distribution and therefore the applicability of analogues. This case of study consider the Numidian turbidite system (Oligocene-Miocene) of Sicily - for many the type example of thick massive submarine sandstones. The tectonostratigraphic setting of the Numidian is analogous to the Angostura (Trinidad) - Scotland (Barbados) sand systems of the Caribbean and associated ultra-deep water exploration. New mapping and detailed sedimentology in the Nebrodi and Madonie Mountains (northern Sicily), allied to existing and new biostratigraphy data, challenge conventional ideas on the Numidian turbidite system as a whole. Rather than having being deposited within an unstructured foredeep by relatively unconfined flows, we show that Numidian deposition was strongly confined by active structures. The system was controlled by thrust related folds and their intrabasin submarine slopes, together with basin-floor architecture inherited from the under-filled passive continental margin. Thrust-top basins filled diachronously implying a large scale tectonic control both on sand fairways and facies variations along their margins. Existing models wrongly suggest that facies variations between adjacent outcrops on Sicily (and elsewhere) result from long-range stratigraphic variations being juxtaposed by later large-displacement thrusts. Our research reveals a much simpler tectonic structure but a more complex stratigraphic arrangement for the Numidian on Sicily - a characteristic of confined turbidite systems.

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Fault-controlled dolomite bodies as geofluid reservoirs and paleotectonic indicators: new insights from Gargano Promontory outcrops

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Keywords: Maiolica Formation, dolomitization, Cretaceous tectonics, carbonate reservoir, porosity.

The Upper Jurassic to Lower Cretaceous platform-slope to basinal carbonate strata cropping out in the Gargano Promontory (southern Italy) are partly dolomitized. Although these dolomite bodies were discovered and mapped a half century ago, they have so far not been comprehensively characterized. This study relies on fieldwork and laboratory analyses (petrographic, geochemical and petrophysical), and aims at characterizing the distribution of the dolomite bodies within the carbonate succession, their dimensions, geometries, textural variability, chemical stability, age, porosity, genetic mechanisms and relation with tectonics.

The investigated dolomite bodies range from meters to kilometers in size, are fault- and fracture-related, and likely formed during the Early Cretaceous at < 500 m burial depths. The proposed dolomitization model relies on mobilization of low-temperature (< 50°C), modified marine formation water that circulated along faults and fractures. During the Cenozoic exhumation of the Gargano carbonate succession, dolomite bodies were partly dedolomitized by meteoric waters, especially in their peripheral zones.

Distribution and geometries of dolomite bodies provide new evidence for Early Cretaceous brittle tectonics in southern Italy, as NW-SE to E-W striking paleo-faults, from meters to 10's of kilometers in size, and likely with normal to right-lateral strike-slip kinematics.

As dolomitization increases by up to 7% the matrix porosity and, hence, can improve the geofluid storage capacity of tight, platform-slope to basinal limestones, the results have a great significance for characterization of hydrocarbon reservoirs, for instance those of the Adriatic offshore area, many of which are hosted in similar dolomitized carbonate successions.

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Fracture characteristics in Cretaceous platform and overlying ramp carbonates: an outcrop study from Maiella Mountain (central Italy)

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Keywords: fault damage zone, vertically persistent fracture, fracture stratigraphy, fluid flow, hydrocarbon

This contribution focuses on field- and laboratory-based characterization of vertically persistent fractures that are part of oblique-slip normal fault zones and crosscut the Cretaceous platform and overlaying ramp carbonates outcropping at Maiella Mountain (central Italy). The achieved results show that: (i) fault damage zones are wider and more densely fractured in the platform carbonates than in the ramp ones; (ii) joints and sheared joints composing the fault damage zones are taller, better connected and less spaced within the former rocks than in the ramp carbonates. The aforementioned structural differences are interpreted to be a consequence of the different mechanical properties of the platform and ramp carbonates during failure. At Maiella Mountain, platform carbonates are, indeed, made up of overall stiffer and less porous rocks, due to more abundant intergranular void-filling cement and presence of matrix.

In terms of hydrocarbon flow and recovery, geometric and dimensional attributes of fractures suggest that the well-connected network of closely spaced fractures cutting across the platform carbonates may form efficient pathways for both vertical and horizontal hydrocarbon flow. In contrast, the relatively poorly connected and low-density fracture network affecting the ramp carbonates is likely less efficient in providing fairways for flowing hydrocarbons.

Mechanical characterization of gas bearing turbidite sands by CIU/CID triaxial tests in Hoek cell for subsidence effects evaluation

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Keywords: Subsidence analysis, triaxial tests, regional geological model, geomechanical simulation.

Potential subsidence induced by off-shore hydrocarbon exploitation must be carefully assessed to prevent environmental impact and potential infrastructure damage. Numerical coupled techniques, based on the integration of geological, fluid-flow and geomechanical models, have been widely used for subsidence evaluation purposes. Their predictive reliability is strongly affected by the availability of consistent and dependable geotechnical parameters for reservoir formation characterization, which are leading parameters in subsidence phenomena evolution.

The present work focuses on the set-up and development of laboratory tests aimed at obtaining the strain and shear strength parameters of gas bearing turbidite sands (Pleistocene) typical for medium-low depth fields in the northern Adriatic sea.

During hydrocarbon production, reservoir pore pressure decreases as a consequence of fluids extraction, leading to consolidation processes of the producing formations: isotropically drained and undrained triaxial tests have thus been performed to reproduce the in-situ stress field in terms of effective stresses (ó' = 5 - 7.5 - 10 MPa). Triaxial tests have been performed within a 38 mm diameter Hoek cell by means of a high-stiffness 500 kN load frame. The setup of the experimental procedure involved sample preparation, saturation, consolidation and shear (drained and undrained): a dedicated saturation panel connected to the Hoek cell was designed for pore pressure control during every phase of the analysis.

Laboratory tests provided cohesion, friction angle and Young modulus of reconstructed samples obtained by representative sands. Within a subsidence analysis process, these parameters were adopted to populate 3D geological and geomechanical models, which were set up at regional scale to represent the stratigraphic framework of the area from the sea bottom to the carbonate substratum.

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Seismic interpretation and hydrocarbon prospectivity along the Veslemøy High, SW Barents Sea

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Keywords: seismic interpretation, hydrocarbon, Veslemøy High.

In recent times, hydrocarbon prospectivity along the Veslemøy High have been unsuccessful. Two exploration wells drilled in the area (7218/11-1 and 7218/8-1) show little or no evidence for commercial hydrocarbon. This is a consequence of the general lack of good quality data to constrain and understand the potential of the area. In this study, we have used a 3D seismic data to reconstruct the geology of the area and reassess the hydrocarbon potential of the Veslemøy High.

The methods used for this research include seismic interpretation of several horizons, faults, multiple seismic attributes analysis, and the calculation of the hydrocarbon in place based on sands distribution. The sand bodies were identified by systematically mapping homogenous, high amplitude, continuous and low variance coefficient packages on RMS amplitude, envelope, variance, and reflection strength time slices.

The interpreted horizons correspond to the Jurassic, Cretaceous and several surfaces of Cenozoic age. Faults include rotated extensional fault blocks, which are predominant on the western flank of the high and small-scale faults found above the regional Cretaceous unconformity. The predicted sand fairways show more or less N-S trend, an indication that the sediments were sourced from the northern part of the study area. The three prospective sands are (a) Eocene sands, which are interpreted below the clastic wedges (b) Miocene sands found at the base of the clastic wedges and (c) Pliocene sands, which are mapped within the clastic wedges. The Eocene sands are basin floor turbidite sands sourced from the Stappen High. Compartmentalization within the sands is linked to the presence of several fault blocks with estimated STOIIP for the three sand bodies being 156, 397 and 32 MMBBL.

This study found that the western flank of Veslemøy High has potential for hydrocarbon. Hydrocarbon reservoirs in the area were deposited in Cenozoic during the breakup of the Norwegian and Greenland Seas.

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Raman spectroscopy: an insight into the chemical short-range order of kerogen for the assessment of thermal maturity

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Keywords: Raman spectroscopy, dispersed organic matter, thermal maturity, diagenesis.

The assessment of thermal maturity in sedimentary successions is crucial for a correct calibration of thermal modelling. Uncertainties in thermal maturity can thus strongly affect the reliability of geological studies on sedimentary basins, and may negatively influence decisions in hydrocarbon (HC) exploration. Vitrinite reflectance is the most used thermal parameter used to calibrate thermal history of a geologic succession, nevertheless, many limitations can affect its reliability. Based on this assumption, in this work, we propose and alternative multimethods approach based on different thermal maturity indicators carried out from the analyses on both the organic (e.g. Pyrolysis Rock Eval, Fourier Transform Infrared Spectroscopy) and the inorganic (e.g. clay mineralogy, low-temperature thermochronology) fraction of sediments.

Derived data have been coupled in order to calibrate a totally novel thermal maturity parameters derived from Raman spetroscopic analyses on the organic fraction of sediments. New Raman parameters have been correlated with different levels of organic matter maturation and on different kinds of organic matter (OM) in four areas characterized by Paleozoic, Mesozoic and Cenozoic successions.

Samples from four different areas have been analyzed: the Lower Congo basin (offshore Angola), the Carpathians fold-and-thrust belt and the Podolia region (both in Ukraine), and the Holy Cross Mts (Poland).

Our results demonstrate that Raman investigation on kerogen for thermal maturity assessment in diagenesis is a powerful tool because it is not time-consuming, can be performed on bulk kerogen or directly on plugs prepared for organic petrography and provides a quantitative assessment on the short-order range structural changes that can occur during thermal maturation of kerogen.

More in detail, five quantitative parameters carried out from the analyses of the Raman spectra show very high correlation against thermal maturity. In detail three parameters (D/G area ratio, RA2 and D/G width ratio) vary regularly with increasing thermal maturity of undifferentiated kerogen, whereas D-G distance, FWHM-G show significant changes with respect to the type of materials (e.g. vitrinite, bulk kerogen, graptolites) analysed. Moreover two successful parameterizations against vitrinite reflectance have been determined and expressed by linear equations.

In conclusion this work widens to diagenesis the application of Raman spectroscropy on low-maturation organic matter, a technique that up to now has been systematically applied only to anchizone and epizone for metamorphic rocks. The physical-chemical meaning of the spectra and related bands in diagenesis are discussed in the framework of the existing literature.

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Permeability enhancement due to fluid overpressure during fault creep: insights from rock deformation experiments on carbonates

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Keywords: brittle creep, friction, fluid pressure, permeability, lab experiments.

Fluid overpressure is one of the primary mechanisms for tectonic fault slip. This mechanism is appealing as fluids lubricate the fault and fluid pressure, Pf, reduces the effective normal stress that holds the fault in place. During underground injection procedures it is fundamental to understand the fluid pressure level required for promoting fault reactivation, the associated type of slip behaviour (i.e. fault creep vs. fast acceleration) and the evolution of permeability with fault slip. In this context, an increase in fault permeability has the potential to induce fault leakage and the loss of the integrity of the reservoir seal. Here, we use laboratory experiments, conducted on a biaxial apparatus within a pressure vessel (Scuderi & Collettini 2016) on limestone fault gouge, to evaluate fault creep evolution as a function of a step increase in fluid pressure and monitor the evolution of fault gouge porosity and permeability. In this suite of experiments we reached 90, 80 and 70% of the maximum shear strength and then we induced fault slip by increasing fluid pressure. Fault creep is slow (i.e 0.001μm/s) away from the maximum shear strength. In this stage permeability is still low (~10-18 m2) and porosity remains constant. For small increases in fluid pressure fault creep gradually increases, inducing an increase in fault porosity that enhances fluid flow and consequently permeability increases. For larger fluid pressure build-ups, when the fault is approaching the critical value for reactivation on the Mohr-Coulomb failure envelope, we observe episodic accelerations/decelerations that in some cases evolve to small dynamic slip events. Fault permeability increases until a full dynamic slip rupture nucleates, which causes gouge layers to compact and porosity to decrease. Our data suggest that fluid overpressure can increase aseismic creep enhancing fault permeability until the development of frictional instability that causes permeability to decrease. Our findings have major implication on reservoir stability and integrity since we document that excess in pore fluid pressure can enhance fault creep, which causes fault permeability to increase with the potential for reservoir leakage.

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The tectono-stratigraphic context of carbonate petroleum systems in the Adriatic

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Keywords: Adriatic, hydrocarbon exploration, petroleum systems, carbonate reservoir.

The Adriatic Sea contains a number of oilfields hosted within Mesozoic carbonate reservoirs. Recent licensing rounds, combined with the acquisition of new regional 2d seismic datasets, have resulted in renewed exploration interest in the area. Efficient exploration will require understanding the basin's geological evolution and learning the lessons of the significant activity carried out between the 1960s and the 1990s. Petroleum systems across the region have developed within the context of two major geodynamic events: the failed Liassic rifting associated with the formation of the Tethys Ocean, and the Tertiary compression that resulted in the development of the foreland thrust belts that define the limits of the Adriatic Sea.

Liassic rifting resulted in the breakup of a widespread epeiric evaporitic-carbonate shelf and established the Mesozoic paleogeography, consisting of the Umbria-Marche-Adriatic basin with the Apulian platform to its SW and the Dinaride platform to the NE. Source rocks were deposited locally within these systems, either within interplatform lagoons or deeper intraplatform basins, whilst carbonate reservoirs developed in a wide range of environments from basinal calciturbidites, through slope breccias and calciturbidites to shallow marine limestones of the platform margin and interior. Early secondary diagenetic processes were important in enhancing reservoir quality and include karstifcation of shallow marine carbonates and dolomitisation of basinal and slope deposits. Limited seal development also occurred during this phase, particularly within the basinal environment.

Tertiary compression developed in two stages: Oligocene thrusting occurred along the NE margin of Adria and resulted in development of the Dinarides-Hellenides and the associated foredeep, whilst later Pliocene thrusting along the SW margin resulted in development of the Apennines. Thrusting overprinted the Mesozoic paleogeographic framework ultimately resulting in the present day configuration of the Adriatic Sea and surrounding landmasses. In petroleum system terms, these events resulted in a switch from carbonate depositional systems to the dominantly fine-grained clastics that form a regional topseal across the basin, whilst high sedimentation rates associated with foredeep development also drove hydrocarbon generation and migration. Locally, carbonate deposition continued for a time over paleohighs and these deposits can form high quality reservoirs. Active compressional tectonics resulted in the main phase of trap development within the basin and improved reservoir quality through pervasive fracturing.

Successful future exploration will necessitate understanding both main phases of the geological development of the basin and identifying areas where overprinting of the two phases produces conditions favourable to the creation and preservation of hydrocarbon accumulations.

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From fracture analysis to flow simulations of fractured carbonates: the case study of Roman Valley Quarry

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Keywords: Bolognano Formation, Fractured Carbonates, Discrete Fracture Network, Hydraulic Properties.

The Roman Valley Quarry located at the northern termination of the Majella anticline in central Italy contains an excellent exposure of bitumen-bearing faulted carbonates, and therefore provides the opportunity to assess the role of stratigraphic and structural heterogeneities on subsurface flow. The vertical walls of this quarry expose in 3D the inner structure of two oblique-slip normal faults oriented WNW-ESE (called the SW and NE Faults). These faults crosscut the Oligo-Miocene Bolognano Formation, which is a medium- to high-porosity limestone (Cilona et al., 2014). The SW Fault has a seismically detectable throw of 40 m, and consists of a continuous main slip surface, with fault rocks that vary along strike from clast- and cement-supported cataclastic rock to un-cemented breccia. Using the bitumen distribution as a tracer of hydrocarbon migration, it is inferred that this fault behaved as both a barrier-conduit and distributed conduit for fluid flow. Conversely, the NE Fault, which has a sub-seismic throw of 8 m, consists of a fractured zone where several smaller slip panels interact, forming a continuous damage zone. This fault is composed of discontinuous pods of intensely deformed limestones and small slip surfaces surrounded by less-deformed rocks. Each slip surface represents a likely conduit to fault-parallel fluid flow, and taken together, these planes constitute a distributed conduit permeability structure (Agosta et al., 2010).

Laboratory measurements and very detailed Discrete Fracture Network (DFN) models are integrated to quantify matrix and fracture contribution to porosity and permeability within each of the lithofacies cropping out in the study area. DFN models were constrained by spatial and dimensional properties of fractures obtained by scanline surveys. These models, calibrated with the field observations, were used to calculate fracture permeability and porosity based on the Oda upscaling method.

Finally, the obtained hydraulic properties were used to build an outcrop-scale static model of both the matrix and the fractures, accounting for their stratigraphic and structural heterogeneities. The model served as input to dual porosity-dual permeability flow simulations to test fluid pathways for various flow scenarios. We show that fluid crossing a fault characterized by a discontinuous low-permeability fault core may bypass reservoir fluid for a range of fault core permeabilities.

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Quantitative Analysis of Pore-Network and Permeability Estimation in Deformed Porous Carbonate Grainstones

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Keywords: Porous Carbonates, X-Ray Microtomography, Permeability, Fluid Flow Simulation, Lattice-Boltzmann.

This study investigates the pore-network properties and the permeability of deformed porous carbonate grainstones located in Northwestern Sicily and Abruzzo region, Italy. Even though the studied grainstones present similar values of porosity, their permeability varies between three to four orders of magnitude. In order to explain this permeability difference, we performed a three-dimensional quantitative analysis of the pore-network including porosity, pore connectivity and specific surface area. For assessing those properties, samples of deformed carbonate grainstones were scanned implementing X-ray computed microtomography techniques. In addition, permeability was computed by means of Lattice-Boltzmann simulation. The effect of each pore-network property (porosity, specific surface area, pore connectivity) on permeability was evaluated by means of scatter plots considering both host rocks and deformation bands.

In the highly porous host rock, the permeability is mainly controlled by the specific surface area, which is linked to both grain size and roughness. Within deformation bands, permeability reduction is related to low pore-network connectivity caused by compaction and cementation.

SESSION S19

Basin analysis: qualitative and quantitative approaches from paleoenvironmental reconstructions to burial history

CONVENERS AND CHAIRPERSONS

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Eugenio Carminati (Università di Roma La Sapienza)
Simonetta Cirilli (Università di Perugia)
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Salvatore Giammetti (ENI)
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Thermal and structural imprint of the Cretaceous ophiolite obduction in Oman

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Keywords: thermal constraints, strain analysis, ophiolite thickness, Oman.

The Oman Mts. preserve Permo-Mesozoic continental margin and deeper-water sediments that were emplaced onto the Arabian Continent during the Late Cretaceous together with the Semail Ophiolite, a portion of the Neo-Tethyan oceanic crust and upper mantle. Passive margin sequences cropping out in the Jabal Akhdar Dome (JAD) and some 50 km south of the dome (i.e., at the front of the Oman Mts. Belt) were investigated by X-ray diffraction of the clay size fraction of sediments and by structural analysis of calcite ooid-rich grainstones to evaluate the thermal evolution and strain of the sub-ophiolite rocks. Both paleothermal and structural data were used to estimate the thickness and extent of the obducted ophiolites onto the Arabian passive margin.

The sedimentary succession from the northern flank of the JAD shows a clay mineral assemblage characterized by long-range ordered mixed layer I-S with an illite content between 85 and 90% and the occurrence of pyrophyllite and/or paragonite, suggesting maximum paleotemperatures consistent with deep diagenetic conditions (150-200 °C). On the southern flank of the JAD, temperature dependent clay minerals indicate lower maximum paleotemperatures, ranging between 120 and 150°C, suggesting a decreasing ophiolite thickness towards the south.

The northern ooids are moderately deformed by a combination of plastic deformation and pressure solution mechanisms, and are sandwiched between marble mylonites, which display higher strain. The ooids show a clear component of flattening and small amounts of stretching in the z-x plane (parallel to the stretching lineation and perpendicular to the foliation). The orientation of the lineation is 015/25 (trend/plunge). Thus, the reconstructed strain ellipsoid is slightly oblique (at a 30° angle) with respect to the NE-SW emplacement direction of ophiolite units.

Several extensional ductile and brittle kinematic indicators show a top-to-the NNE shear direction nearby the ooid sampling sites. These observations suggest a major role of syn-exhumation extensional tectonics that may have overprinted evidences of previous overthrusting. The ooids at the southern flank of the JAD are largely undeformed.

The paleotemperatures of 150-200°C evidenced by clay mineral assemblages from the northern boundary of the JAD are consistent with the onset of the plastic behaviour of calcite, that, at such temperatures is accompanied also by pressure solution mechanisms. Lower temperatures between 120° and 150°C, occurring in the southern flank of the JAD are consistent with the brittle behaviour of calcite and with the absence of deformed ooids.

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Unraveling the coast line in the Po Plain-Northern Adriatic region during the late Messinian sea level drop

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Keywords: Po Plain, Messinian Salinity Crisis, 3D-backstripping, Coast line.

The Po Plain-Northern Adriatic foreland basin (PPAF) offers an unique record of the late Messinian Salinity Crisis (MSC) in the Mediterranean region in various geological settings consisting of deep-water turbiditic basins and a series of marginal and intra-slope basins, including the foreland. Most studies on the MSC have focused on the western and eastern offshore Mediterranean Sea whereas few studies have focused on the onshore areas; the marginal position and the syn- to post-Messinian tectonic activity shaped a more complex context to study. A majority of these studies interpret a progressive evaporation of the basin during the acme of the MSC, estimating a sea level drop of 1000 to 1500m, based mainly on erosion surfaces identified in seismic imaging. In the PPAF the stratigraphic relationships into a decompacted Messinian coastal wedge, suggest that the total lowering of the relative base-level did not exceed 900m (Ghielmi et al., 2013).

The aim of this study is to apply the 3D backstripping technique to restore the vertical position of the Base Pliocene regional surface at the PPAF. The results are compared with the coast line position at that time derived from seismic and lithofacies studies (Eni data). The new topography and bathymetry are calculated as the result of flexural isostatic compensation of Plio-Quaternary sediment removing and water column changes during the maximum MSC lowstand. To perform the backstripping we make use of TISC software (Garcia-Castellanos*,* 2002) to calculate the vertical flexural isostatic motions with an elastic thin plate approach and laterally-constant lithospheric elastic thickness. The surfaces used as inputs are: DEM by TOPO30 project, latest Messinian unconformity (after interpretation of Eni seismic lines for the local framework) and top of the Mesozoic carbonate succession. The required parameters into the decompaction algorithm are calculated from lithological log analysis on the deepest hydrocarbon wells (Eni data), reaching the complete pre-Messinian sedimentary succession.

Our restored surface and the resulted coast line position after the considered 850m relative sea level drop, agrees and supports previous studies on facies associations distribution of the entire PPAF. In addition in the northern sector of the PPAF, a network of valleys can be observed, extending several tens of km and linked to the foredeep where turbidite systems persisted in the deeper zones throughout the whole MSC.

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High-resolution Plio-Pleistocene chronostratigraphy of the Friulian-Venetian basin by seismic and well-log correlations

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Keywords: Plio-Pleistocene, Friulian-Venetian basin, chronostratigraphy.

The Friulian-Venetian Basin (FVB) is the north-eastern portion of the wider Po Plain-Adriatic foreland, which bounds the whole Italian peninsula to the East, and is the place where most of the Italian hydrocarbon fields occur. The present-day architecture of the FVB is the result of the inherited Mesozoic sea-bottom topography which evolved during Cenozoic in the foreland basin shared by three different collisional systems: the Dinarides, the Southern Alps and the Northern Apennines.

This work provides a high-resolution chronostratigraphic framework for the upper Neogene subsurface succession of the VFB since the early Zanclean regional transgressive surface to the latest Pleistocene, using a 2D reflection seismic lines grid and well log correlations (by spontaneous potential and resistivity signals) from Eni E&P dataset. The detailed sequence-stratigraphy analysis was based on the allogroups, (i.e. major stratigraphic units bounded at base and top by regional tectonically-induced unconformities, related to the Northern Apennines foredeep north-east migration), and on their lower rank units of climate and tectonic origin, recognized by Ghielmi et al. (2013). The almost absent deformation of the FVB sedimentary succession after Messinian well preserved the succession and allows handling the subsequent 3D basin scale interpretation. To get a high chronostratigraphic resolution we have performed a complete biostratigraphic revision of the ca. 1km-long continuously cored Venezia 1 well, integrated with near, correlatable onshore and offshore hydrocarbon wells to cover the entire Plio-Pleistocene sedimentary record.

During Middle-Late Pleistocene, glaciations affected the whole Po Plain-Adriatic basin consequently suffered long periods of sea-level lowstand with large siliciclastic sediment supply followed by smaller transgressive events due to the shorter interglacials. This basin-wide short-term cyclicity is still not fully defined, but some geometries of the transgressive-regressive cyclothems are visible in seismic. In detail, into the Venetian shelf, cross-correlation panels show how the cycles can be correlated each other by well-log signals and linked to Global Eustatic sea-level curve.

The resulting new age model, obtained merging biostratigraphy, seismics, direct (bottom cores) and indirect (well log) sedimentological data like electric logs, provides a new high-resolution subsurface chronostratigraphic frame for the Venetian-Friulian and Northern Adriatic basin, especially useful to date the uppermost part of the FVB Pleistocene clastic sediments, made by Milankovitch-type cyclothemes.

Ghielmi M., Minervini M., Nini C., Rogledi S. & Rossi M. 2013. Late Miocene-Middle Pleistocene sequences in the Po Plain-Northern Adriatic Sea (Italy): The stratigraphic record of modification phases affecting a complex foreland basin. Marine and Petroleum Geology, 42, 50-81.

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Burial and thermal evolution of the Sicilian fold-and-thrust belt: preliminary results from the Scillato wedge top basin (central-northern Sicily, Italy)

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Keywords: Scillato basin, thermal history, Ro%, XRD on clay minerals, wedge-top.

Wedge top basins are key elements for unravelling the tectonic evolution of fold-and-thrust belts. In detail, their thermal signature and sedimentary fill records modes and time of exhumation of their edges.

The Scillato basin is a wedge-top basin located in the central-northern sector of the Sicilian fold-and-thrust belt (western sector of the Madonie Mts). Upper Serravallian-upper Tortonian succession composed by up to 1,200 m thick delta-river to open marine siliciclastic sediments, fills the basin. This succession lies on a deformed substrate made up of thrust sheets composed of Numidian Flysch, Sicilidi and Imerese units stacked with a SW tectonic transport. The basin fill records a polyphase tectonic evolution with two non-coaxial compressional to transpressional tectonic events since the middle-late Miocene that caused changes in basin geometry, uplift of local structural highs and creation of new source areas for sediments.

Organic matter optical analysis and X-ray diffraction of clay minerals have been performed from the basin fill and the substrate to unravel source to sink evolution.

The organic matter shows two separate clusters of vitrinite reflectance (R_o%) in the basin fill. The first one has values of 0.4-0.5 R_o% with an increase of thermal maturity with depth. The second one has values of 0.7-0.8 R_o%, indicating reworked, more mature kerogen. The substrate shows higher R_o% values: from 0.6% in Numidian Flysch up to 0.9 % at the base of the Imerese unit.

XRD on clay minerals presents, among the other phases, two population of mixed layers Illite-Smectite (R0 and R1 stacking order) in the wedge top basin. The first population, R0, indicates thermal maturity levels in agreement with the R_o% and is authigenic; the second one, R1, has detrital origin. The substrate shows R3 in the older formations of the Imerese unit and R1 in younger formations of the Imerese unit and Numidian Flysch.

Coupling the results from the organic and inorganic fine fractions of the studied sedimentary successions, it has been possible to: 1. quantify the maximum sedimentary/tectonic loads and exhumation the wedge top and the substrate underwent; 2. identify, at least, two distinct source areas for the basin fill changing through time: the Numidian flysch in the initial stage of the basin development and the Imerese unit in the final stages of basin filling.

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A Jurassic-Cretaceous intraplatform basin in the Panormide Southern Tethyan margin (NW Sicily, Italy), reaveled by integrating facies and structural analyses with subsidence history

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Keywords: Jurassic, Cretaceous, Panormide platform, NW Sicily.

We illustrate the tectono-sedimentary evolution of a Jurassic-Cretaceous intraplatform basin in a fold and thrust belt present setting (Cala Rossa basin).

Detailed stratigraphy and facies analysis of Upper Triassic-Eocene successions outcropping in the Palermo Mts (NW Sicily), integrated with structural analysis, restoration and basin analysis, led to recognize and describe into the intraplatform basin the proximal and distal depositional areas respect to the bordered carbonate platform sectors.

Carbonate platform was characterized by a rimmed reef growing with progradational trends towards the basin, as suggested by the several reworked shallow-water materials interlayered into the deep-water succession. More, the occurrence of thick resedimented breccia levels into the deep-water succession suggests the time and the characters of synsedimentary tectonics occurred during the Late Jurassic.

The study sections, involved in the building processes of the Sicilian fold and thrust belt, were restored in order to obtain the original width of the Cala Rossa basin, useful to reconstruct the original geometries and opening mechanisms of the basin.

Basin analysis allowed reconstructing the subsidence history of three sectors with different paleobathymetry, evidencing the role exerted by tectonics in the evolution of the narrow Cala Rossa basin.

In our interpretation, a transtensional dextral Lower Jurassic fault system, WNW-ESE (present-day) oriented, has activated a wedge shaped pull-apart basin.

In the frame of the geodynamic evolution of the Southern Tethyan rifted continental margin, the Cala Rossa basin could have been affected by Jurassic transtensional faults related to the lateral westward motion of Africa relative to Europe.

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Multidisciplinary approach for outcropping and subsurface Permian-Cenozoic deep-water carbonates (Central Sicily): outcome for paleogeography of the Southern Tethyan continental margin

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Keywords: Permian-Cenozoic stratigraphy, deep-water carbonates, surface and well-log data, seismic calibration.

An integrated stratigraphic study of the outcropping and buried Permian-Cenozoic deep-water carbonate successions have been performed. These successions form some of the tectonic units**,** mostly buried beneath the Late Neogene sedimentary cover**,** in the fold and thrust belt of Central Sicily.

Three main successions, pertaining to the well known Lercara, Imerese and Sicanian domains, have been reconstructed on the basis of a detailed facies analysis, seismostratigraphic interpretation, biostratigraphy (mostly based on palynological data) and comparison between outcropping and subsurface deep-water sediments.

The main results reveal a continuous sedimentation of the deep-water Southern Tethyan Sicilian succession since the Permian to Cenozoic. In detail:

a) the Permian-Middle Triassic terrigenous and carbonate deep-water successions, outcropping or buried in the Cerda, Lercara-Roccapalumba and Sosio Valley regions, are well comparable to each other and represent the common substrate of the Mesozoic-Paleogene Imerese and Sicanian carbonate successions;

b) the Mesozoic-Paleogene deep-water carbonates, when compared among them, reveal the occurrence of different sedimentary successions (Imerese and Sicanian);

c) the Oligo-Miocene foreland basin terrigenous sediments (Numidian flysch) clearly differ from the coeval foreland hemipelagic to open-shelf carbonates.

The paleogeographic reconstruction envisages:

a) during the Permian-Triassic, a wide subsident continental rifting area, bordered by a shallow-water domain periodically supplying the basin with calciturbiditic to gravity flows sedimentation (rift stage of the Southern Tethyan margin);

b) during the Jurassic-Paleogene, two different deep-water basins developed in a context of a post-rift stage. The different sedimentation reflects the location of the Imerese and Sicanian basins, respectively, along adjacent rimmed shelf and stepped carbonate platform margins;

c) the Oligo-Miocene sedimentation reflects the afore-mentioned different location of the two deep-water domains. Flysch deposits suggest that the Imerese was located near an accretionary prism, differently the Sicanian open-shelf carbonates and marls developed on a still undeformed foreland.

Characterization and palaeoenvironmental reconstruction of geothermally-controlled microbial carbonates in a tufa system (Triponzo, Central Italy)

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Keywords: Surface Analogous, Microbial Carbonates, tufa deposit, Central Italy.

Recent discoveries of Cretaceous Pre-salt hydrocarbon reservoirs in the subsurface of the South Atlantic, offshore Brazil and West Africa, have led to an increased interest about microbial carbonates accumulated in continental rift basins. Despite numerous and significant studies, the current knowledge about non-marine carbonate facies models, processes and products of subaqueous and subaerial spring-related carbonate precipitation is still limited, especially about the various precipitation processes (inorganic, biologically controlled and microbially mediated) taking place in continental aquatic settings, where the biologically induced and influenced mineralization is controlled by a complex interaction of multiple factors (geochemistry, hydrology, microbial communities…). A better understanding of depositional and spatial models of carbonates in continental rift settings can be achieved by extracting spatial information from present-day systems to produce predictive tools for subsurface exploration of such carbonate reservoirs. Triponzo (central Italy) is a small village situated on the Nera River and characterised by the presence of a Quaternary, partially dismantled barrage tufa system and an active small thermal spring located upstream of the tufa site. Along the right bank of the Nera River, several small outcrops characterised by the presence of 6 unusual carbonate facies stratigraphically correlable with the tufa system are present. Sedimentological, petrographic and geochemical analyses evidence their microbially-mediated origin and their strict correlation with the local geothermal circulation along the present fault/fracture network. Their spatial distribution inside the depositional system allow to correlate each recognized facies to precise previous palaeoenvironmental conditions. The study of the Triponzo microbialites can contribute to the better knowledge of the biologically-influenced mineralization and microbially-mediated processes leading to the carbonate deposition in the non-marine carbonates realm.

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Thermal constraints to the tectonic evolution of the SW Zagros (Fars province) along a 250 km transect from internal to external zones

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Keywords: Thermal constraints, thin-skinned vs. thick-skinned tectonics, Zagros.

The Fars province of the Zagros Mountains is famous as one of the largest hydrocarbon reserves worldwide, and also as a territory rich of high quality outcrops. Geological cross-sections of the Zagros belt are usually based on regional geological maps (1:1.000.000 or 1:250.000), and on a few subsurface data. In this work, we present a 253 km long cross-section through the Fars province, constrained by original vitrinite reflectance and temperature-dependent clay minerals data and based on detailed geological maps (1:100.000 scale), new fieldwork data, well stratigraphic logs and seismic lines.

Thermal data show that the sedimentary cover the Fars province, experienced similar levels of thermal maturity from the internal (Interior Fars) to the external zones (Coastal Fars) in early-late diagenetic conditions. 1-D thermal models display a decreasing lithostatic load towards the foreland from 3.6 km to 3.2 km for the Bangestan Group and indicate that sedimentary burial is the main factor affecting thermal maturity.

Surface and subsurface data suggest that at depths, thick-skinned deformation reactivates and dissects the regional detachment level, developed along the evaporitic Hormuz series. The Arabian basement deformation occurs by crustal-scale thrusts, with a wavelength of 70 km. Within the sedimentary cover, positive and strike slip inversion of ancient normal faults is documented. In some cases, rift-related normal faults control the location and trajectory of younger thrust planes, in others normal faults are translated and rotated by thrusts and folds development.

The cross section obtained merging all the datasets allowed us to highlight that deformation of the 10–12 km thick sedimentary cover of the Arabian margin is generally thin-skinned and characterized by thrusting-related folding, with a wavelength of about 14 km.

The average shortening value is 7%, with a tectonic style is strongly heterogeneous along the cross-section. The outermost sectors display shortening values between 7% and 9%, whereas the internal sectors show much lower shortening (4.4%). These differences are associated with and seem to be controlled by facies and thickness lateral variability, i.e., thicker successions and occurrence of more stiff facies, such as the Tarbur Fm limestones in the areas characterized by lower shortening.

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Contained-reflected turbidites and Slurry Beds in the Tufiti di Tusa Formation. Examples from Lucanian Apennines (Southern Italy) and their significance

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Keywords: Contained-reflected turbidites, slurry beds, Tufiti di Tusa Formation, Southern Apennines.

Preliminary stratigraphic and sedimentological studies of the Tufiti di Tusa Formation (APAT, 2007), a siliciclastic, volcanoclastic and calciclastic turbidite succession outcropping in the Lucanian Apennines (Southern Italy), have been carried out.

This stratigraphic succession, which shows many similarities with other Rupelian volcanoclastic successions in the Northern Apennines, revealed the presence of: (1) medium to fine grained sandstone beds with sedimentary features such as alternations of plane or wavy and parallel laminae with ripples and convolute laminae, or diffuse presence of biconvex ripples with cross-sigmoidal laminae and hummocky-type structures; these structures show different palaeocurrent directions from one other and in comparison with those indicated by the sole casts; (2) tripartite beds composed of: (a) a basal medium to coarse-grained massive to crude laminated sandstone; (b) an intermediate poorly-sorted muddy sandstone with pseudonodules, water escapes, and mudstone clasts; (c) an upper thin fine-grained laminated sandstone with load structures.

The beds referred to in point (1) are consistent with the occurrence of contained-reflected turbidites related with flows confined within basins that were too small for sustained unidirectional flows and that favoured multiple deflections or reflections from basin-margin slopes (Pickering & Hiscott, 1985). The beds referred to in point (2) resemble tripartite slurry beds produced by flow transformations of turbidity currents previously enriched in mud through erosive processes; their occurrence was related with intrabasinal topographic highs and depocentres with slope changes, which favour mud erosion and decelerations (Tinterri et al., 2016). The stratigraphic distribution of all these beds will be used as main instrument for a reliable interpretation of the basin physiography evolution (Tinterri et al., 2016).

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Evidence for Early Cretaceous syn-sedimentary tectonics in the Umbria-Marche Basin (Northern Apennines, Italy)

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Keywords: Early Cretaceous tectonics, Clastic deposits, Umbria-Marche Basin, Monte Primo Ridge.

Under-investigated Barremian-Aptian detrital intercalations embedded in pelagic deposits of the Umbria-Marche-Sabina Domain (Central and Northern Apennines, Italy) are here presented. The study sector corresponds with the Mt. Primo area (Umbria-Marche Ridge, Northern Apennines), where three stratigraphic sections of the Maiolica and Marne a Fucoidi Formations were sampled. Here, gravity-driven breccias and calcarenites (the latter interpreted as debris-flows, or turbidity flows if graded) are embedded in pelagic sediments. The massive lensoid-to-tabular levels are interbedded with the typical tethyan pelagic mudstones of the Maiolica Fm. and with the marly lower portion of the overlying Marne a Fucoidi Fm., forming as a whole a >60 m-thick interval. The microfacies analysis allows to recognize rudstone-to-floatstone and grainstone textures, dominated by mm- to cm-sized lithoclasts and associated with loose grains of benthic foraminifers, dasycladal algae, microbial crusts, *microproblematica* and bivalves. The latter components indicate productive photozoan-type carbonate platform(s) as source area(s). The lithoclasts are made of: i) Lower Jurassic and Lower Cretaceous shallow-water carbonates; ii) Jurassic mudstones and wackestones referable to the pelagic Umbria-Marche succession; iii) Maiolica-type soft pebbles (with and without calpionellids). The occurrence of primitive hedbergellids in the lowermost sampled pelagic levels, coupled with the occurrence of *Montseciella arabica* and *Suppiluliumaella polyreme* in the coeval resedimented material, suggests a Barremian-early Aptian age for the detrital interval.

Evidence for abundant resedimented material in pelagic basins are generally related to tectonic perturbations of the depositional setting, to eustatic oscillations, or both. In our opinion the analyzed deposits are related to extensional tectonics for several reasons: i) sudden switch in the succession from pelagic mudstones to a very coarse-grained interval; ii) the abundance of Cretaceous benthic material, sourced from an unknown carbonate platform, coupled with lithoclasts of shallow-water carbonates, which suggest tectonic back-stepping and dismantling of platform margins; iii) the occurrence of Calcare Massiccio lithoclasts along with Jurassic and Lower Cretaceous pelagites; such evidence necessarily implies a tectonic exhumation and erosion of a Jurassic pelagic carbonate platform located nearby the study area, which was buried in the earliest Cretaceous.

Direct and indirect evidence for an extensional phase in the late Early Cretaceous are documented in several sedimentary successions of Italy. Our data fit well with this widespread, but poorly studied tectonic phase and, at the same time, provide new implications for the Early Cretaceous paleogeography of the Umbria-Marche Basin.

The Terni "corridor": new stratigraphic constraints for the reconstruction of the Jurassic paleogeography of Central Apennines

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Keywords: Geological mapping, Jurassic paleogeography, Umbria-Marche-Sabina succession, Terni basin, tectonics.

This paper is an outcome of a field-mapping project encompassing the Sabini, Martani and Narnesi-Amerini Mts. Here, Meso-Cenozoic rocks referable to the Umbria-Marche-Sabina succession are unconformably overlain by Neogene-Quaternary marine-to-continental and volcanoclastic deposits. During field-work, our attention was focused on the analysis of Pelagic Carbonate Platform (PCP)/Basin systems, in particular on the identification of Jurassic submarine paleoescarpments and of facies associations, these being the key tools for understanding the original Jurassic-Early Cretaceous architecture of the local depositional system and its tectono-sedimentary evolution.

The Terni area is crucial for appreciating the influence of inherited structures on younger deformation (Neogene-Quaternary). The present-day geological setting of the Terni basin is that of an intermontane basin, bounded by Plio-Pleistocene normal faults and filled with lacustrine-to-continental deposits of the Tiberino basin. Surrounding it, however, the Mesozoic inherited elements and their original (Jurassic-to-Early Cretaceous) relationships are well-preserved.

As a result of the Early Jurassic rifting stage, a huge shallow-water carbonate platform (Lazio-Abruzzi Platform) characterized the eastern sector of the study area (present-day coordinates), passing west-ward to a slope and basinal setting with intra-basinal highs (respectively, Sabina and Umbria-Marche-Tuscany Basins).

Abundant neritic material was resedimented in the deeper-water environments, and the dispersion patterns mirrored the sea-bottom rift topography. The widest PCP recognized in the area is the Sabina Plateau, a N-S trending fault-bounded high passing east- and north-ward to the Sabina Basin via steep paleoescarpments. In particular, the N or NW-dipping escarpment of the Sabina Plateau is exposed near Terni, facing the Terni plain. Opposite to this across the Plain, the *circa* S-dipping Jurassic paleoescarpment of the Poggio Cisterne Vecchie PCP is well-exposed on the southern slopes of the Martani Mts. These Jurassic paleo-structures imply the existence of a Jurassic basin in the subsurface of the Terni Plain, as marked by: i) unconformable contacts between the horst-block Calcare Massiccio (silicified) and the Jurassic-Lower Cretaceous olistolith-bearing hangingwall-block pelagites; ii) neptunian dykes. The existence of an arm of the Sabina Basin branching westwards (the Terni "corridor") is constrained by the occurrence of shallow-water material embedded in Lower-to-Upper Jurassic basin-fill pelagites exposed in the Amelia Ridge. This post-lower Pliensbachian resedimented material implies a productive carbonate platform (Lazio-Abruzzi Platform) other than the Sabina Plateau, which was already drowned, as the source-area. The Narni Ridge, in contrast, during the Jurassic was effectively shielded by the huge Sabina Plateau from the influx of shallow-material shed by the Lazio-Abruzzi Platform.

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The Evaporite Deposits from the Catanzaro Trough, Calabria, South Italy: results of a study of fluid inclusions and, organic and inorganic inclusions hosted by gypsum

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Keywords: Fluid inclusions, Catanzaro Trough, Gypsum crystals.

Fluid inclusion studies of gypsum crystals from the Catanzaro Trough (Calabria, Southern Italy) evaporite deposits are used to investigate the origin of the deposits and also to assist with palaeoclimate reconstructions. The deposits formed during the Messinian Salinity Crisis (~about 6 Ma) and consist of twinned gypsum crystals that are centimetric to millimetric in size (Cianflone et al., 2012). Petrographic analyses reveal the presence of abundant primary and secondary fluid inclusions (FIs). Primary FIs (Costanzo et al., 2012), trapped along crystal growth zones, are mainly monophase liquid, showing elongated and irregular morphologies and ranging in size from 10 to 100 micron. Secondary FIs, trapped along annealed crystal fractures, occur throughout the crystals and range in size from 2 to 40 micron displaying irregular morphologies. Growth zones hosting primary FIs alternate with zones devoid of inclusions, this may reflect temperature variations that in turn lead to alternations in gypsum growth zone rates *e.g.* fast rate (abundant FIs present) and slow rate (no FIs). UV microscopy revealed the presence of organic matter within the primary FIs which indicates a primary origin for the gypsum deposit. In addition to the FIs gypsum crystals also contain: a) organic fragments *i.e.* peloids and coccoliths and b) aluminium hydroxide (gibbsite?) along fractures and in the body of the crystals. The peloid and coccoliths inclusions are marine in origin. The aluminium hydroxide is continental in origin (Bilonizhka et al., 2012) and can come from many sources such as bauxite soils, or from weathered metamorphic basement. The characteristics of the fluid inclusions present in combination with the trapped organic (peloids and coccoliths) and inorganic (aluminium hydroxide) materials have the potential to assist with: 1) palaeoclimate reconstructions, 2) basin analysis and, 3) sequence stratigraphy. Furthermore, the study of primary FIs reveals the hydrochemistry of surface brines from which the gypsum precipitated.

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Costanzo A., McNulty E., Feely M., Lowenstein T., Dominici R. & Melgarejo J.C. 2012. Evidence for microbial life in deep time: a geomicrobiological investigation using fluid inclusion studies. Rendiconti Online della Società Geologica Italiana, 21 (2), 1080-1082.

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Preliminary study of Halite-hosted Fluid Inclusions from the Evaporite Deposits of the Crotone Basin, Calabria, Southern Italy

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Keywords: Fluid inclusions, Crotone Basin, Halite crystals.

Fluid inclusion studies of halite crystals from the Crotone Basin (Calabria, Southern Italy) are used to interpret the evolution of the Basin. The halite crystals, formed during the Messinian salinity crisis (~6Ma), display a range of morphologies and sizes (range from millimeters to centimeters in length) and contain primary fluid inclusions (FIs) with trapped organic chemical species. Halite deposits are classified into three different facies i.e. banded facies (microcrystalline halite), white facies (macrocrystalline halite) and clear facies (macrocrystalline halite). These facies match the "Saline pan cycle" shown by Lowenstein et al., 1985. The banded microcrystalline halites correspond to a "flooding stage", the white macrocrystalline halites correspond to an "evaporite concentration stage" and the clear macrocrystalline halites correspond to a "desiccation stage. Petrographic analyses reveal the presence of abundant primary and secondary fluid inclusions. Primary FIs (Goldestein, 2003; Costanzo et al., 2012), trapped along crystal growth zones, are mainly monophase liquid with negative crystal shapes (ranging in size from 20 to 100 micron). In details, FIs are classified in type 1, type 2 and type 3. Type 1 inclusions are Liquid + Vapour (L+V), Type 2 inclusions are Liquid + Vapour + organic matter, Type 3 are Liquid + Vapour + solid halite crystals. Secondary FIs, trapped along annealed crystal fractures, occur throughout the crystals and range in size from 2 to 40 micron displaying irregular morphologies. Laser Raman Microspectroscopy on organic rich FIs (Type 2) generates raman spectra with peaks attributable to organic chemical species, in particular the carotenoids lutein and lycopene groups. In summary, we present morpho-structural, petrographic and microspectroscopy studies which allow us to elucidate the origin and evolution of these evaporite deposits.

Costanzo A., McNulty E., Feely M., Lowenstein T., Dominici R., Melgarejo J.C. 2012. Evidence for microbial life in deep time: a geomicrobiological investigation using fluid inclusion studies. Rendiconti Online della Società Geologica Italiana, 21 (2), 1080-1082.

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A quantitative multi-method approach to assess thermal evolution of the Lower Congo Basin (Angola)

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Keywords: Thermal modelling, vitrinite reflectance, clay mineralogy.

Vitrinite reflectance has been always considered the most reliable thermal maturity indicator in sedimentary basins to reconstruct robust burial and thermal history. This is a key topic to correctly assess the timing and amount of hydrocarbon generation and expulsion. Nevertheless the reliability of vitrinite reflectance measurements can be affected by many external factors that change from basin to basin (e.g., organic facies features, temperature and pressure conditions) leading to wide uncertainties in thermal modelling calibration and, thus, in the evaluation of the risk.linked to the petroleum charge. We demonstrate that in case of vitrinite suppression, due to H-rich kerogen, and/or vitrinite retardation, due to overpressure in siliciclastic successions, the classical Sweeney and Burnham kinetics adopted in commercial softwares do not match the actual thermal evolution of the basin. In these cases, thermal evolution can be successfully modelled using a complementary multi-method quantitative approach based on the integration of XR diffraction on fine grained sediments, Fourier Tansform Infrared (FT-IR) and Raman spectroscopy on dispersed organic matter. In detail, smectite illitization kinetics and more appropriate kinetics for organic matter maturation (e.g., PresRo™ and T-P-Ro) can be integrated to evaluate the effect of pressure where pressure data are available (Carr, 1999; Zou et al. 2001; Cuadros, 2006).

This approach was applied in the Lower Congo Basin where 32 cuttings from a 5 km-deep well drilled in the Upper Oligocene-Miocene Malembo formation have been analysed to derive organic and inorganic constraints to model the basin thermal evolution. Vitrinite and bitumen reflectance measurements show values between 0.3 and 1.0% along the well, with underestimated values in the overpressured interval or in H-rich kerogen, that make the models derived from this indicator alone, ambiguous. On the other hand, the illite content in mixed layer I-S ranges between 35 and 88%, passing from R0 to R1 to R3 stacking order with increasing depth and can be modelled according to a geologically sound thermal history, using Cuadros' kinetics. Furthermore quantitative parameters of organic matter thermal maturity, derived from FT-IR and Raman spectroscopy, record a regular distribution against depth and reinforce the modelled thermal history derived from mineralogical data alone, overcoming pitfalls of vitrinite reflectance calibrated models.

In detail, present-day temperature distribution through the well indicates a geothermal gradient of about 40°C/km and measured pressures show an overpressured interval between 3 and 4 km depth. Retardation and suppression phenomena affected vitrinite reflectance in this interval but did not influence smectite illitization.

In conclusion, he tested multi-method approach demonstrates the need to integrate different indicators of thermal maturity and their kinetics when modelling sedimentary successions in case the risk due to petroleum charge must be carefully assessed and reduced.

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Geological 3D modelling and quantitative Basin Analysis. Workflow, methods and results in the central Po Basin

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Keywords: 3D geological model, 3D velocity model, Po Basin.

In the modern geosciences, quantitative basin analysis studies need the basic support of consistent and comprehensive 3D geological models able to describe and represent, as closely as possible, the geological complexity of the studied area.

An integrated workflow for 3D model building only from subsurface data has been designed, implemented and tested in the central part of the Po Basin (in the framework of the EU funded GeoMol Project, ISPRA, 2015). The workflow includes several phases that can be summarized in: i) Data acquisition, interpretation, harmonization; ii) Elaboration of the 3D model in time domain; iii) Calculation of the 3D velocity model; iv) 3D model time-depth conversion; v) Consistency check and refinement of the 3D model in depth domain; vi) Construction of the final 3D geological model and parameterization.

The 3D modelling workflow is designed to manage input data (e.g. seismic lines, well sonic log and stack velocity data, well stratigraphy markers) in different domains of the z axis (time and depth), and includes also independent analysis (e.g. gravity interpretation) that can support the consistency check and refinement of the 3D model.

The most critical point of the workflow is the management of the velocity data, the calculation of the velocity model, and the time-depth conversion. We consider the 3D instantaneous velocity model as the best approach when dealing with a basin characterized by high facies and thickness variability, and high structural complexity (e.g. Alpine foreland basins or large intermountain basins).

We present the input dataset (12,000 km of seismic lines and 130 wells, provided by ENI S.p.A.), the different steps of the workflow, with special focus on the management of the velocity data and on the construction of the 3D instantaneous velocity model, and the role of the gravity anomalies study (i.e. high pass filtered Bouguer anomaly map) on the model refinement.

The final 3D model (5,700 km^2 wide, with a vertical extension from 5 up to 13 km) includes 178 faults and 128 patches related to 15 horizons (formation top or unconformity surface), from Triassic to Pleistocene. The high detail of the 3D model supported the quantitative analysis of the relationship between sedimentation and tectonic, both at local and basin scale (Maesano & D'Ambrogi, 2016), the characterization of structural elements and active faults, the better definition or new identification of seismogenic sources.

This new 3D geological imagery of the central Po Basin is freely discoverable and accessible to the scientific community through standard metadata and Web Map Services (INSPIRE compliant) related to 3D model-derived maps, and as a whole 3D model through an interactive 3D-Explorer (www.geomol.eu).

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Martian fluvio-lacustrine deposits: 2D and 3D sedimentary modeling and implications for the climate and the astrobiological potential of the planet

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Keywords: Mars, fan-deltas, modeling, climate.

During the last years, the availability of high resolution topography, imagery, and hyperspectral datasets of the martian surface led to the discovery and detailed geological studies of tens of ancient fluvio-lacustrine deposits. Among the latter deposits, deltaic systems are the most prominent evidence suggesting the existence of long-lasting bodies of standing water during the early Mars history. Furthermore, deltas might be key to understanding potentially habitable periods in Mars history. However, despite their significant paleoclimatic implications, the open questions about the formation and evolution of martian deltas often make their climatic/hydrologic interpretations unclear. In fact, it is unclear whether martian fluvio-deltaic deposits formed during extended epochs of clement climatic conditions (and thus if they are unequivocal indicators of favorable conditions for life) or during limited and episodic climatic optima produced by regional factors, like for example impact craters, volcanism, or tectonics and resultant hydrothermal activities (and thus if they could have been formed also under climatic conditions not necessarily different from present Mars thus likely prohibitive for life).

Here, a modified version of state of the art terrestrial model Sedflux whose concepts have been successfully tested in several different terrestrial settings, is used for the quantitative study of the hydrology and sedimentology of martian deltas. Input files for the simulations are derived from remote sensing imagery and topography and essentially are: the bathymetry of the receiving basin and the water and sediments discharges at the mouth of the river opening into it. The spatial resolution of the simulations is typically 1-5 m in the vertical, and 10-100 m in the horizontal when operating in 2D-mode. Processes represented by the model there are: surface plumes, bedload transport, sediment slope failure, turbidity currents, debris flows, subsidence, compaction, water base level changes, sediment remobilization due to waves and currents, and subaerial erosion and deposition by river on the delta plain. Output files include three dimensional grids of sediment property, bathymetric slope, water depth, grain size distribution, etc.

Results of the sedimentary characterization of a significant portion of the more than 50 known martian deltas, obtained by using different combinations of water discharges, sediment load, until matching the observational evidence of the case studies, point to formation timescales in the order of 10^2-10^3 years. These latter results suggest that deltas might have not been exclusively formed during extended epochs of clement climatic conditions and thus that they do not necessarily imply the occurrence of favorable and durable conditions for life, raising the question on whether paleolakes with fan-deltas shall be considered as ideal landing sites for future in situ exploration of Mars.

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Lake General Carrera/Buenos Aires, Chile/Argentina, as terrestrial analog for martian short-lived lakes

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Keywords: Lake Carrera/Buonos Aires, fan-delta, deglaciation, Mars, modeling.

Due to climate change and the last major deglaciation of the northern Patagonian ice sheet, Lake General Carrera/Buneos Aires (LGC/BA, Chile/Argentina) experienced significant hydrological modifications which resulted in a more than 400 m vertical retreat of the lake during the last 20-15k years. The latter overall retreat was punctuated by at least 6 highstands which are all testified by a series of six stacked fan-deltas in the southwestern part of the lake. In this study, the latter region of LGC/BA is investigated in detail through fieldwork campaign and analysis of remote sensing datasets, including ASTRIUM Pleiades satellite stereoimages from which a high-resolution (1 m/pixel) digital elevation model (DEM) has been derived.

One of the aim of the present study is to gain a better quantitative understanding about the sedimentology of fan-deltas forming under rapidly and abruptly changing water level for application to the numerical modeling of martian fan-deltas. In fact, the site provides access to a concentrate of present and past coastal lacustrine morphology, erosional and depositional features such as beach ridges, strandlines, and terraces which can be directly compared with Martian putative deposits and associated features. In this regards, the sedimentary deposits in LGC/BA are particularly interesting since they can be used to test fluvio-deltaic sedimentary catastrophic scenarios characterized by a) high water and sediment discharges (due to glacial retreat and ice-melt) and b) rapid and significant water level changes (due to break of ice dams and fast draining of the lake). The latter conditions are rather representative of those under which short-lived ($<10^3$ yrs) impact crater lakes might have formed on Mars with catastrophic mechanisms due to regional factors, like for example impact craters, volcanism, or tectonics, resulting in bursting groundwater ice melting determining high sediment and water discharges under climatic conditions not necessarily different from those of present Mars. Whereas the ice dam breaches occurred at LGC/BA could be compared to the breaching of impact craters visible at many martian impact crater lakes characterized by the presence of outlet channels. Finally, the feature at LGC/BA are among the best ideal analogs for Martian lacustrine features also because they are relatively young and thus they have experienced less amount of erosion and post-depositional modifications.

Results from the forward simulations of martian fan-deltas using the Sedflux 2.0 code (Hutton and Sivytski, 2008) are presented and compared to the results from remote sensing analysis and fieldwork campaign at LGC/BA sedimentary complexes, which provide Earth-validated observational and numerical constraints for the modeled processes.

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Upper Miocene/?Pliocene photic-zone carbonate/siliciclastic facies in the Northern Simbruini Mts. (Abruzzo-Central Apennines)

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Keywords: Central Apennines, mixed carbonate/siliciclastic, Neogene, late-orogenic, corals.

In the northern Simbruini Mts. (Oricola-Rocca di Botte area, AQ) of Central Italy, the Neogene terrigenous stratigraphy represents a geological *unicum* in the region, with features described here for the first time. Overlying the Bryozoan limestone, the "*Orbulina* marls" pass upwards to a marl/sandstone alternation ascribable to the apenninic foredeep sedimentation of the Latium-Abruzzi Domain. In our study area, an array of lithologies exist, which are unknown in the terrigenous successions of Central Apennines. These include coral-bearing arenites and conglomerates, sandstones with large bivalves and gastropods, red algal/bryozoan bindstones with corals and other benthic biota, and conglomerates made essentially of Mesozoic pelagic lithoclasts. Although the outcrop conditions are generally very poor, it has been possible to reconstruct a general stratigraphy based on the age and the lithology of the examined rocks, determined through the paleontological analysis of >60 samples collected across an area of less than 1 km², including two core samplings. Marls and shaly marls with *Orbulina* are generally lower Tortonian, and have been ascribed to the "*Orbulina* marls" unit, while the sandstone-bearing interval is upper Tortonian /? lower Messinian. The marls and the Bryozoan limestone are unconformably overlain by sparse patches of a siliciclastic conglomerate/arenite, bearing corals, bivalves, large gastropods and coralline algae along with clasts of pelagic limestone, chert, mesozoic platform carbonates and planktonic forams-rich marly intraclasts. Although their age is not precisely determinable, the composition of these deposits coupled with field mapping, suggests that their sedimentation took place in late-orogenic times. Only the uplift, subaerial exposure and erosion of large portions of the stratigraphy which also represent exotic geological domains, and subsequent sediment transport by rivers, can account for the strikingly heterogeneous composition of the conglomerates. Sedimentological characters (i.e.: shape and size of the clasts) suggest reworking of the pebbles in a coastal environment. A shallow water, photic environment is confirmed by the presence of zooxanthellate (*Tarbellastrea* sp.) corals, red algae and abundant macrofauna. The displaced clasts observed in the study area are also instructive, as they also include limestones bored by litophaga, commonly used as markers of a coastline. In conclusion, the available sedimentological and paleobiological dataset suggests sedimentation in a shallow-water environment, close to the shoreline. As such it most likely represents the vestiges of an ephemeral depositional environment, testifying the early emersion from the sea of this tract of the Apennine chain.

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Quantitative Geology and Basin Analysis in the last 30 years

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Keywords: Quantitative Geology, Basin Analysis.

The necessity to quantify natural processes, in the last three decades, was quite important with the focus to extrapolate some measured features to sectors without any calibration point. The goal of these activities was to obtain a prevision of some particular parameter in order to better quantify human activity in the natural world.

Being Geology the natural site to get knowledge about earth evolution, this process involve in a very deep way the geologists in trying to reproduce the natural processes that has to be forecasted. The best way to study the evolution of a process is to develop a numerical model of it, in order to quantify the effects of the process.

This brought to the definition of a new particular part of the earth disciplines that will treat in a numerical way earth evolution, the Quantitative Geology. This means to describe nature with numerical parameters that will always approximate the reality as closer as our understanding increase. It always means also to develop some algorithms that reproduce the natural processes. In addition, in this case the quality of the algorithm increase as our understanding of the processes increase, and the necessity to develop a numerical model will also enhance our knowledge.

Some qualitative theories will be enhanced or neglected if you try to test them in a numerical way; unfortunately, numbers are 'super partes' element of our world. On the other hand being experimental parameters some sampling of a population of data affected by a 'Gaussian' distribution that we cannot sample in its totality, the numerical model will help in outlining the 'out of population' measurement that will not be indicative of that process.

This aspect is important in understanding that the quantitative geology will forecast you the population behavior of a population of data fixed on the identification of a mode. With the Probabilistic quantitative geology, we can also risk the lateral distribution of the population and their effects on the results.

All these issues has been applied to the Basin Analysis procedure for the exploration of hydrocarbon with large investment in the related R&D activities. It cannot be exclude that the same methodologies and the same softwares can be applied to the other disciplines of the quantitative geology as the seismic data collecting and reprocessing is now commonly applied to the medicine world.

Middle Pleistocene fluvial incised valleys from the subsoil of the centre of Rome: facies, stacking pattern and controls on sedimentation

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Keywords: fluvial sequence stratigraphy, incised valleys, Middle Pleistocene, Rome.

A review and correlation of borehole data, mostly from a recent survey of drilling in Rome (Palatino Hill and Fori Romani), and outcrops studies have allowed to reconstruct the stratigraphic architecture of the subsoil. Fluvial lithofacies of the ancient Tiber River system are recognized, which fill three high relief incised valleys of Middle Pleistocene age within of which well dated pyroclastites occur.

These valleys constitute portions of the low rank/high frequency depositional sequences (PG4, PG5 and PG6) forming the Middle Pleistocene to Holocene composite/high rank Ponte Galeria Depositional Sequence (Milli et al., 2016). The latter represents the most recent stratigraphic unit of the Roman Basin. From a lithostratigraphic point of view the low rank sequences have a good correspondence with the Villa Glori, Fosso del Torrino and Quartaccio Synthems (Funiciello & Giordano, 2008) and are correlated to MIS 14-13, 12-11, 10-9 respectively.

Valleys are elongated in N-S direction, and each of them has dimensions comparable to the tributaries valleys developing within the low rank Late Pleistocene-Holocene Tiber Depositional Sequence (Milli et al. in press): 1-2 km in width and up to 50 m in thickness. They are well entrenched into the substratum that is composed of Pliocene-Lower Pleistocene marine clay and Lower-Middle Pleistocene fluvial sediments and pyroclastites. The investigated valley segments are located some 20 km upstream from the coeval shorelines, nevertheless they show an internal stacking pattern of facies recording base level changes, in turn related to the Quaternary climatic and high frequency/amplitude sea level fluctuations.

Each valley infill shows at the base a 10 m thick and laterally continuous body of amalgamated pebbles and sands forming a braided channel belt, deposited under low accommodation conditions and correlated with late lowstand and early transgressive phases. It follows a 20-30 m thick intermediate portion showing sandy-silty deposits attributed to sinuous channel belt, and laterally confined by muddy floodplain deposits, often rich in organic matter (transgressive phase). On the top, the channel sandy facies tend to widen and grade laterally to pedogenized floodplain mud.

The three recognized incised valleys are organized into a compound-composite stack that records their progressive entrenchment and westward migration, in response to regional moderate uplift, to lateral supply from pyroclastic flows sourced by Colli Albani from SE, and to differential erodibility of the substratum.

Funiciello R. & Giordano G. 2008. Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 347 Roma (Eds.). APAT-Servizio Geologico d'Italia, Roma

Milli S., Mancini M., Moscatelli M., Stigliano F., Marini M. & Cavinato G.P. 2016. From river to shelf, anatomy of a high-frequency depositional sequence: the Late Pleistocene-Holocene Tiber Depositional Sequence. Sedimentology, doi:101111/sed.12277.

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Preliminary study of provenance and roundness of volcaniclastic beach sand from Panarea and Stromboli islands (Aeolian Archipelago, Tyrrhenian sea)

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Keywords: Aeolian islands, volcaniclastic sand, roundness, provenance, beach, dacitic signatures.

This work focuses on the compositional and textural characterization of modern sand supplied from two volcanic islands in the Aeolian Archipelago, with particular attention given to the factors that control grain rounding. Panarea and Stromboli islands provide a good opportunity to define the provenance signatures of detritus eroded from various types of lava and fragmental pyroclastic debris. Detrital modes were defined for the medium-sand fraction of each sample, and three samples were selected for more detailed analysis to detect potential grain-size dependence of composition by also counting very coarse, coarse, fine and very fine grain size fractions. A total of 400 points was counted per slide using the Gazzi-Dickinson method. Changes in grain roundness were assessed to evaluate grain resistance to transport (currents and wave abrasion). A numerical value was assigned to very angular (1), angular (2), sub-angular (3), sub-rounded (4), rounded (5), well-rounded (6). The mean roundness was calculated for all grains encountered during point-counting using a slightly modified version of the technique of McBride and Picard (1987). Lithic fragments (lathwork and microlitic textures), discriminated by color groundmass (Lvlblgl+Lvmiblgl:Lvlbrgl+Lvmibrgl:Lvlgrgl+Lvmigrgl), show the differences between the erupted products from Panarea and Stromboli. Lithic-rich Stromboli sands have basaltic and andesitic composition signatures, whereas lithic-rich Panarea sands have a wider range of composition signatures, namely from basalt (lesser amount), andesites to dacitic. The latter, classified as a new lithic compound, Lvlgrgl, defined by sand-sized crystals of feldspar and quartz set in a grey glass groundmass. In general, the most common roundness category among all the grains from both islands is 2 (angular), immediately followed by 3 (sub-angular), 1 (very angular) 4 (sub-rounded), and then with a very low occurrence of 5 (rounded), and no 6 (well rounded) grains. This is probably a function of the continuous clastic supply from the Stromboli slopes. The maximum length of stream transportation on these islands is fairly short (3-3.5 km). We noted that after only 3 km of transportation from the stream setting to the beach (from the crater to the coast), the mean roundness grains change from 2 (angular) to 3.5 (sub-angular/sub-rounded). We have also determined that certain grain types tend to round more quickly in beach environments, such as olivine and pyroxene among the monocrystalline grains and Lvmi among the lithic grains. All of this, in turn, will help in understanding the provenance of ancient volcaniclastic sequences in the stratigraphic record which may have been influenced by coastal reworking.

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Determining reservoir heterogeneities in turbidite fans by integrated sedimentological and stochastic analyses – a comprehensive study of the Bordighera deep-sea-fan

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Keywords: turbidite fan, sub-depositional environments, facies heterogeneities, hybrid event bed distribution.

The Upper Cretaceous Bordighera Sandstone (Ligurian Alps) is addressed as a potential analogue for sand-rich distributive turbidite fans comprising depositional elements ranging from braided submarine channels to terminal splays. High-resolution facies analysis identifies the system as a basin floor fan being subject to pronounced facies heterogeneities - interpreted as a consequence of combined intrinsic controls on sandbody stacking patterns and extrinsically controlled intercalating calcareous sedimentation of the calcareous San Remo Helminthoid Flysch. Limited lateral outcrop exposures facilitates a comprehensive approach incorporating both conventional facies analysis and statistical analyses of facies distributions in order to better determine cyclicity and to decipher various depositional sub-environments within the siliciclastic fan. Furthermore, the inherent complexity of spatial arrangements of reservoir-analogous sandstone bodies is illustrated through determinations of inferred degrees of confinement and the resulting facies distributions and reservoir-analogous architecture.

The system is characterized by markedly abrupt facies changes within short distances along flow paths, interpreted as the consequence of complex interplay of the degree of confinement and allogenic controls such as variations in sediment supply and related changes of stacking patterns. While proximal depositional sub-environments are dominated by cyclically arranged amalgamated channel-fill successions (characterized by lenticular stratal geometries), the distal part is denotative of a complex compensational stacking hierarchy of tabular sandbodies interpreted as the result of a decrease in the degree of confinement. Additionally, this medial to distal loss on confinement is coupled with a pronounced increase in hybrid event bed abundance. Careful analysis of contrasting lateral and longitudinal amalgamation ratios provide further insights into distinct axis- to off-axis trends in facies distributions. In addition, investigations of down-dip trends in basal grain size distribution reveal the strong variability in sediment transport capacity within the system.

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Why is the Numidian a confined turbidite system?

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Keywords: Numidian system, confined turbidites, active basin, facies variations, outcrops.

Mediterranean turbidite systems are deposited adjacent and within developing orogens and there has been an increasingly recognition of the role of active structures within basins and their influences on facies distribution. Some turbidites basins such Marnoso-Arenacea in northern Italy, regarded to have been deposited in tectonically quiescent settings are now seen as influenced by advancing thrust fronts of the orogeny. Here we show outcrops examples on how active basin floor can control the facies distribution on a turbidite basin. This study case comes from the Nebrodi and Madonie Mountains (northern of Sicily), a region that contains the greatest expanse of Numidian strata (Oligocene-Miocene) in the central Mediterranean. The system was controlled by thrust related folds and their intrabasin submarine slopes, together with basin floor architecture inherited from the under-filled passive continental margin. We also demonstrate that deforming basin-floor can be revealed by entrainment of substrate into the sand-fairways. Thrust-top basins filled diachronously implying a large scale tectonic control both on sand fairways and facies variations along their margins. Existing models wrongly suggest that facies variations between adjacent outcrops on Sicily (and elsewhere) result from long-range stratigraphic variations being juxtaposed by later large-displacement thrusts. Our research challenge this ideas and propose a much simpler tectonic structure but a more complex stratigraphic arrangement for the Numidian on Sicily. We outline the evidence for this deduction and develop the consequences for understanding of the Maghrebian orogenic system that has deformed this margin during the Neogene.

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Depositional evolution and diagenetic process of Barik reservoirs (Mahatta Humid area outcrops, Oman)

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Keywords: depositional environments, diagenesis, Barik reservoirs.

The sandstone intervals of Barik formation are considered as large tight gas reservoirs in Oman, which has been developed in the Khazzan Field to produce 1 bcf/d of gas by end 2017. Although, Barik reservoirs have been under study and development for more than 20 years, the understanding of their distribution is still uncertain regarding their lateral continuity and heterogeneity. As analogue of the subsurface data, the Barik formation exposes extensive sandstone bodies, red mudstone and green shale extended up to 2 km in length and up to 8.5 meters height.

This work is based on 1) intensive outcrop study with detailed logging and facies description, 2) high resolution gamma-ray profiles.

According to 3D representative field data, five lithofacies have been identified in the Barik formation in Mahatta Humid area (Oman) 1) through cross-bedded fine-medium grained sandstone units with rip-up clasts, 2) planar cross-bedded fine grained sandstone, 3) current rippled and wave rippled fine grained sandstone with evaporate-crystal casts, 4) parallel laminated fine grained sandstone units, 5) mudstone.

According to the detailed description of the lithological and sedimentological characteristics three depositional units have been identified for Barik Formation: shoreface, costal sabkha and meandering fluvial deposits.

The oldest exposed were deposited on the shoreface zone suggested by the presence of typical traces fossils (*Diplocraterion*) and current wave structures of sandstone together with casts of evaporite-crystal up to 20 cm thick. The values of total gamma-ray widely fluctuate from 641,5 ppm to a 1146,9 ppm.

Sea level must have had gradually falling as the second unit is characteristic of a costal plane environment where costal sabkha and meandering fluvial system environments dominated. Costal Sabkha is recognized by the presence of thick red mudstone units alterned with thin grayish-green shale and fine grained sandstone units with thin casts of evaporite-crystal. Typical gamma ray values for costal sabkha range from minimum 1100 ppm to a maximum 1419 ppm. Finally meandering fluvial deposits filled multichachannelyzed system recognized by erosive contacts and succession of large-scale through cross-bedded sandstone and planar cross-bedded sandstone beds. Gamma-ray values decrease from a 1109,7 ppm on the channel base till 609 ppm on the channel top.

Preliminary field data for diagenetic alterations illustrate well developed carbonate and silicate concretions, scattered and grouped crystals. Concretions depending on size, spatial distribution and depositional environments influence the effective porosity being a critical factor of reservoir quality deterioration of Barik reservoirs.

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Tidal sedimentation recorded in volcanoclastic deposits filling a peripheral seaway embayment (early Miocene, Sardinian Graben System)

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Keywords: Sardinian Seaway, Miocene volcaniclastics, tidal circulation, embayment infill, facies analysis.

The Sardinian Graben System was a part of a NE-SW-oriented extensional basin, rotated after a counter-clockwise gyre into a N-S-elongate basin, as consequence of the eastward migration of the Apennine orogenic front, in the western Mediterranean during the Neogene.

Starting from the early Miocene, the Sardinian Graben was inundated by marine waters, turning into a seaway. Possibly, the Miocene Sardinian Seaway was characterized by a tidal circulation, promoted after the connection between the Atlantic Ocean (to the west) and the Paratethys Ocean (to the east), as a southern minor branch of the well-known peri-Alpine tidal seaway.

In this work, we investigate an area located marginally to the mid-seaway, whose well-exposed sedimentary deposits record the local expression of a tidal amplification occurring in a coastal peripheral embayment of the wider Sardinian Seaway.

The studied succession is ca. 120 m thick and includes three main units: (i) the 20-m-thick lowermost unit consists of terrestrial polymictic conglomerates, erosionally overlain by shallow-marine large-scale cross-stratified sandstones; (ii) the second unit is 60-70 m thick and includes heterolithic sandstones and mudstones, exhibiting a variety of tidal sedimentary structures, including inclined stratification, reactivation surfaces, tidal bundles, flaser bedding, etc.; (iii) the uppermost unit is 20-25 m thick, abruptly overlies the previous deposits on to a sharp surface and is made up of open-shelf mudstones.

Our facies analysis, based on stratigraphic logs, correlation panels and line-drawing, as well as thin section observations on each recognized facies, suggest the following evolution for the study sector.

Initially, a marginal-marine sedimentation along this border of the graben system favored the progradation of two adjacent deltaic systems separated by a tectonic high: (i) a fan delta impinging the coastal area from east-northeast, and (ii) a river delta prograding from west. During a subsequent phase, the possible isolation of a part of this coastal area, probably generated by the building of some beach barrier, produced a tidal amplification and the onset of a barred tidal flat/ tide dominated delta platform over the previous wave-dominated delta. Finally, a regional-scale marine transgression provoked the inundation of this coastal area and the tide-dominated regime changed into open marine, shelf conditions.

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Sensitivity analysis of the parameters of the Erosion Potential Method: the case of the Estero Morales, Chile

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Keywords: sensitivity analysis, erosion potential method.

The production and transport of sediments at the basin scale is one of the most important variables to consider in the quantification of the effects of land use change, definition of risk areas, and for prioritizing interventions at the basin scale. Because sediment transport is expensive and difficult to measure in the field, multiparametric numerical models are commonly used to assess sediment yield. To improve performances and reliability of the models, it is crucial to identify the set of input parameters that are more sensitive than others in determining the results of the model.

This study reports on a sensitivity analysis of the parameters involved on a model of sediment yield. The study site (Estero Morales) is located in the upper valley of the Rio Maipo in the Andes (Central Chile). The Estero Morales drains an area of 26 km^2 and features an average slope of 35°. It consists mainly of volcano-metamorphic rocks and conglomerate-sand deposits of gravitational and moraine origin. The vegetation is confined to only a small riparian portion and near the small village of Baños Morales close the confluence with the Volcan River.

The sensitivity analysis is aimed at identifying parameters of the Erosion Potential Method (EPM) model, that are most influential in the calculations and thus require detailed investigation in order to improve the performance of the model. The model considers parameters such as temperature, rainfall, land use, lithology and morphology of the basin. More than 500 calculation simulations were carried out, changing each of the 5 above-mentioned parameters in a wide range of values. Results show the greater influence of the lithological parameter, which was quantified and divided objectively into classes, assigning to each class a value of coefficient of specific erosion properties of the rocks. Finally, an analysis of sediment yield under potential scenarios was conducted, especially imposing a maximum value to the most influential parameters of the model, in order to assess sediment yield during extreme high-magnitude events.

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Serravallian-Tortonian transition in the Cilento basin: multiphase sliding events as sedimentary expression of regional tectonic events during late Miocene

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Keywords: Cilento Group, olistostrome complex, slumps, prograding wedge, Southern Apennines.

In Cilento area (southern Apennines, Italy) exists a rare example of an exceptionally well exposed Miocene turbidite complex, the Cilento Basin (CB), a typical mixed siliciclastic/calciclastic turbiditic suite, spanned the time between Langhian to Tortonian, outcropping over an area of 600 sq. km (Cavuoto et al., 2004).

During upper Serravallian-Lower Tortonian basin fill exhibits a vertical/lateral transition from relatively confined basin medium-grained channelized deposits to upward coarsening and thickening sheet-like turbidites couplets across flat, unconfined basin floor, finding by successive unevenly spaced thick gravity-flow deposits. The deposits thickness (associated carbonate megaturbidites and olistostromes) demonstrate that they took in place during by multiphase catastrophic marine landslides, associated with contemporaneous instability of shelf margin or slope. Exceptionally huge olistostrome crops out at the eastern margin of Gelbison Mt. on area of 40-50 Km^2 and presents a thicknesses that range between 30 and 100 m and sediment volumes that range from 1,5 to 5 km^3. The vertical and lateral heterogeneity of the upper olistostrome (OL2), is described from a number of localities along a 20 km-long and up to 15 km-wide exposed sectors of the proximal eastern margin of the Miocene Cilento Basin. Detailed field mapping enabled the identification of localities with olistostromes and a stratigraphic organization is recognized in the eastern CB margin where the OL2 show features of a falling-stage, and shelf-edge collapse. It is constitute to four facies: a) Basal debris/mass flow conglomerate with pebbles of crystalline and sedimentary rocks; Disorganized conglomerates with scoured lower contacts (debrites or massflows); b) Plastically fluidized-folded (slump folds) Cretaceous/Paleogene thin bedded shaly limestone turbidites (upper slope facies); c) stratified polychromous thin-bedded turbidites and d) matrix-supported siliciclastic conglomerates.

The internal geometry of the OL2, implies a new hypothesis about their construction: the prominent unconformity which separate the upper olistostrome to a underlying succession of siliciclastic turbidites and marls, may be described as a major boundary underlying a regressive/transgressive systems tracts. Vertically and laterally stratigraphic evolution (facies assemblance), propose a basinwards transition from a sheeted complex, to slope and laterally encroaching bypass deep-water (downslope) megaslide system. Calcareous "megaturbidites" may be tsunamites forebulge-derived (Apenninic Platform Unit) whereas "olistostromes" were associated with onset of extensional tectonic phase in the CB eastern margin, led to the opening of the Tyrrhenian basin and progressive displacement of crystalline nappe of Calabrian arc.

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SESSION S20

Evolution of continental margins and associated basins: insights into stratigraphy, tectonics and volcanism

CONVENERS AND CHAIRPERSONS

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Hydrothermal influences in the Late Triassic Lagonegro Basin (southern Italy): evidence of contemporaneous mid-ocean-ridge spreading in the western Tethys

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Keywords: Norian/Rhaetian, rare earth elements, trace elements, discriminant plots, Ionian Ocean, Lagonegro Basin.

The south-western branch of the Tethys Ocean was interested, during the Late Triassic, by the opening and spreading of an oceanic basin, the Ionian Ocean. Its north-western termination was characterized by carbonatic/siliceous deposition inside the Lagonegro Basin, which was imposed on transitional crust. Three stratigraphic sections of the Lagonegro Basin sedimentary record, representing a proximal-to-distal transect (e.g., Casacci et al., 2016) from the continental margin, have been investigated to evaluate the interaction of this basin with the adjacent Ionian Ocean. This ocean was actively spreading since the Middle Triassic (Passeri et al., 2014) but no investigation has been done on the influence of the ridge activity on its peripheral portion situated northward, represented by the pelagic sediments of the Lagonegro Basin. Three major inputs into the sediment were recorded: detrital clay, biogenic silica and carbonates, and most of the samples here studied consist of mixtures of these components. In order to discriminate the chemical signature of the main fractions, bulk and partition geochemical investigations have been carried out in relation of the three main components of the sediments. The rare earth elements (REEs) reflect different pattern for each sediment fraction with the $SiO_{2\text{-bio}}$ group showing middle REEs enrichment, suggesting Fe-oxyhydroxy influence; the clays group shows a flat pattern typical of shale from siliciclastic input; the carbonate group indicates heavy REEs enrichment and Ce negative anomaly, pointing out seawater influence. Enrichments in hydrothermally derived elements, from the submarine weathering of middle oceanic ridge basalts (MORB), were found in both the clay and carbonate fractions indicating a moderate mixing of the two end-member solutions, hydrothermal fluids and seawater, during the deposition of the Lagonegro Basin sediments. The tectonics of the basin and the different setting for each section left the shallower and more proximal section to the continental margin, without any record of the hydrothermal influence. The results can be considered as a first geochemical evidence of the hydrothermal activity related to the Ionian Ocean ridge, in the Lagonegro Basin deposits.

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Geological mapping and structural setting of the Corte Slices (Alpine Corsica, France)

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Keywords: Structural geology, Alpine Corsica, Corte Slices, exhumation processes.

The Corte Slices belong to the Alpine belt preserved in the north-eastern part of the Corsica island. The Alpine orogen is the result of the closure of the Alpine Tethys and continental collision between the European plate and the Adria plate in the time span between the Late Cretaceous and the Early Oligocene. In the Late Oligocene, the opening of the Ligure-Provencal back-arc basin leads to the anti-clockwise rotation of the Sardinia-Corsica block and the consequent detachment of the Corsica collisional belt from that of Western Alps. The witness of this geodynamic history is a tectonic stack consisting of three groups of units (Lower Continental Units, Schistes Lustrés and Upper Units) which represented both the oceanic and the continental crust accreted to the alpine orogenic wedge at different time and depths. In the mapped area the tectonic setting to the Corte Slices, that belonging to the Lower Continental Units, and their relationships with the Schistes Lustrés, that represent the oceanic and continental crust affected by the high-pressure metamorphism has been investigated. The Corte Slices are made up of a paleozoic basement intruded by permian metagranites, covered by two sedimentary successions: the older one is constituted by mesozoic carbonates ant the youger one by eocenic siliciclastic deposits, showing at their base an angular unconformity. In the study area three units are distinguished taking into account the metamorphic imprint. The westernmost is the Popolasca-Castiglione Unit that is affected by the most pervasive deformation; it is thrust by the Croce d'Arbitro Unit and the by the Piedigriggio-Prato Unit, both less metamorphic. The collected data about the metamorphism suggest that P values of the metamorphic peak calculated for each unit increase from east to west, in contrast to the T values, which increase from west to east. Geological mapping has allowed the identification of three deformation phases, acquired during the continental subduction and the subsequent exhumation that affect the Corte Slices. The proofs of the onset of the exhumaton, that corresponds to the decrease of the pressure value, have been found into the mineral phases growth during the D1 phase. Probably both the D1 and D2 phases were developed during the exhumation in a convergent setting. Only in the late stage of the tectonic evolution of the Corte Slices (D3 phase) the tectonic setting became extensional, due to the collapse of the orogenic wedge. The results of the geological-structural mapping provide new insights for the interpretation of the stacking of Corte Slices in the frame of the geodynamic history leading to the birth of the Alpine collisional belt.

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Evidence of hydrothermal fluid flow in the Adriatic continental rifted margins

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Keywords: hydrothermal fluid flow, Adriatic rifted margin, extensional detachment systems, rock-fluid interactions.

The increasing availability of high resolution seismic data and deep drill hole data from deep-water rifted margins allowed to understand the architecture and evolution of these yet little investigated domains. Nonetheless, their thermal evolution is poorly constrained although the presence of hydrothermal systems seems to play a key role in determining the heat fluxes. Because of the weak metamorphic overprint and the spectacular exposure, the Adriatic paleo-rifted margin actually preserved in SE Switzerland and N-Italy, represent a unique opportunity to observe, sample and understand the fluid flow history recorded in the different rift domains that are from the continent to the ocean: the proximal, the necking, the hyperextended and the exhumed mantle domains. A detailed sampling was carried out on Triassic and Jurassic carbonate rocks along a transect in the Grison region. In the proximal domain high angle fault bounded by tilted blocks are the most common rift structures whereas in the most distal part extensional allochthons lying onto extensional detachment faults are commonly observed. Also syn- to post-rift sediments have been considered. Within this study, the main goal is to investigate breccias, cements, veins and replacement minerals within pre- and syn-rift sediments that could testify the space and time evolution of rock-fluid interactions. Field evidence, petrography and cathodoluminescence investigations reveal a strong heterogeneity in the composition of the fluids moving oceanward. Dolomitization, calcitization and silicification widely characterize the multistage Jurassic evolution of the Adriatic margin as even documented by U-Pb dating (LA-ICP-SFMS) on carbonate. Furthermore, different analytical results point to hot fluid systems. Microthermometry on fluid inclusions (T_h up to 150-160°C) coupled with O and C isotopic values (δ^{13}C -0.23‰ to 3.07‰ VPDB; δ^{18}O -1.01‰ to -12.05‰ VPDB) suggest a hydrothermal origin of the fluids. These data, moreover, are comparable with those of the present-day Iberia continental margin (ODP-Leg-103). Sr^{87}/Sr^{86} isotopic ratios, higher than those of Triassic-Jurassic seawater, imply a fluid-basement interaction. Finally main, trace (e.g. Ba, Cr, Ni, V), rare earth elements and He isotopes, especially from the most distal part of the margin, suggest the presence of fluid pathways involving either the continental crust and the exhuming mantle.

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Nature of crust in the northern Red Sea

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Keywords: Northern Red Sea, rift to drift transition, non-volcanic rift, role of magmatism, core complex.

Axial accretion of oceanic crust accompanied by Vine-Matthews magnetic anomalies started roughly 5 Ma in the southern Red Sea, and 3 to 1 Ma in discrete axial cells within the central Red Sea, but has not yet started in the northern Red Sea, north of the Zabargad Fracture Zone in a pattern suggesting northward propagation of the nascent oceanic rift. The Zabargad Fracture Zone (FZ), a topographic feature running NNE-SSW across the entire width of the Red Sea roughly parallel to the Dead Sea Fault, offsets the Red Sea axis by ~100 km.

However, doubts still remain as to the true extent of the oceanic crust in the northern Red Sea with workers tending to prefer an oceanic regime and workers tending to prefer attenuated continental crust. The lack of organised magnetic anomalies North of the Zabargad FZ, where the coasts are straight, the presence of lower seismic refraction velocities and the presence of Precambrian shield rocks in boreholes near the coasts support the idea that the northern Red Sea is carpeted by stretched and thinned continental crust, with a few isolated sites of basaltic injection. From another viewpoint, given that in the northern Red Sea the plate separation rates are small (of the order of 4-5 mm/a), some other workers suggest that with such slow spreading rates, the absence of organised magnetic anomalies might be due to the blanketing effect of large thicknesses of salt which flow faster than the opening rate. The magnetic anomalies are subdued due to the high heat flow and slow cooling of the intruding rocks.

We show here that magmatism can play an important role even in the evolution of non-volcanic rifts and can help solve the controversy on the nature of the crust in the northern/central Red Sea, i.e., the crust outside the axial oceanic cells is either oceanic or it consists of melt-intruded extended continental crust. Our results are in line with a model whereby asthenospheric melt intrusions contribute to weaken the lower crust enabling crust-mantle decoupling, with extension of the upper crust accompanied by flow of the lower crust into the extending regions and followed by lower crust exumation as core complexes.

Our findings show that continental rupture in the northern Red Sea is preceded by intrusion of basaltic melts with MORB-type elemental and isotopic signature, that cooled forming gabbros at progressively shallower crustal depths as rifting progressed towards continental separation. A 3.5 km-deep magma chamber below Thetis Deep, an axial segment of initial oceanic crust accretion in the central Red Sea, represents melt migrated below rift axis forming shallow olivine-gabbro intrusions and, thus, the final stage in this progression.

Stratigraphic and sedimentary evolution of the Upper Carboniferous-Middle Triassic Malpàs-Sort Basin (central Pyrenees): a facies analysis approach to the paleogeographic reconstruction

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Keywords: Permian, Middle Triassic, facies analysis, continental successions, Western Catalan Pyrenees.

After some pioneering studies during the sixties and eighties of the last century, a few researches have been carried out on the continental Permian to Triassic sedimentary successions of central Pyrenees since the very recent and detailed insights of Gretter et al. (2015) and Mujal et al. (2016). In the frame of these last works, our aim is to clarify and increase the knowledge about some of these continental strike-slip basins to enlarge the stratigraphical, paleontological and paleogeographic, evolution of western peri-Thetys during the Permian and Triassic.

In this study we show preliminary data from the Pont de Suert area (NE Spain) allowing to unravel the stacking pattern, the tectonic evolution of the Late Carboniferous to Middle Triassic sedimentary record. In particular, the so-called Malpàs-Sort sub-basin represents to-date an almost unknown intramontane through with stunning outcrops, to define the sedimentary facies, the tectono-sedimentary evolution and its paleoenvironments.

The Malpàs-Sort sub-basin is filled by four units: the older one is the Erill Castell Fm. (Late Carboniferous), a pyroclastic and volcanic succession composed of light and dark coloured tuffs, breccias and a basaltic andesite sheet (volcanic environment). The maximum thickness is about 550 m. The Malpàs Fm. (Stephanian C, 500 m maximum thickness) consists of greenish/greyish sandstones, coal levels, dark siltstones and small lacustrine limestones. From this unit, the sedimentary records change radically to reddish conglomerates, sandstones and siltstones of fluvial environment of the Peranera Fm. (Permian), which lies unconformably over the previous one showing a maximum thickness of 700 m. The sedimentary fill ends with the Buntsandstein facies (Lower-Middle Triassic); 200 m thick separated by another unconformity and composed of coarse-to-fine fluvial and playa-lake deposits. The thicknesses of Peranera and the Buntsandstein are strongly variable due to the angular relationship between them. Our study reveals that an intense tectonic activity was occurring during the deposition. These preliminary results also allow us to better define the paleogeography in peri-Thetys during the considered time-span.

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Up- and down-scaling field and seismic observations to test models of rifted margins formation

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Keywords: Rifted margins, Alpine Tethys, North Atlantic.

Recent advances in the understanding of rifted margins resulted from the development of new, high-resolution seismic imaging methods, drilling at deep water rifted margins, and field studies of fossil examples in mountain belts. The development of new modelling techniques enabled simultaneously experimentations of some of the parameters controlling the rift evolution. However, the parameters and boundary conditions used in numerical and geophysical models are often not ground truth with direct observations. In the case of deep-water rifted margins, the problem is that drill hole data is expensive, rare and only available from a handful of examples worldwide. In contrast, remnants of former deep-water rifted margins have been described from internal parts of collisional orogens, such as the Alps or the Pyrenees, where kilometre-scale outcrops preserving primary structures of the former distal rifted margins are well exposed. Access to these large-scale outcrops provides direct observations on mantle and crustal rocks and the associated sedimentary sequences and magmatic additions formed in former distal rifted margins. The combination of world-class outcrops, classical field-based mapping and analytical methods in combination with seismic observations of present-day rifted margins enables the testing and calibration of rift models.

In our presentation we will combine seismic and field observations from both present-day rifted margins and fossils analogues preserved in the Alps. We will mainly focus on the description of deformation and magmatic processes and on the relation to sedimentary architecture during final rifting. Key questions that we aim to address are related to the strain and magmatic distribution and the bulk rheological evolution during rifting in the crust and sub-continental mantle. Eventually, we will discuss how far the inherited mantle composition and rift-related mantle processes may control the rheology of the mantle and the magmatic budget before, during and after lithospheric breakup.

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The NW Sicily Channel: space-time migration of the orogenic front

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Keywords: tectonic inversion, transpression, compression, Sicily Channel.

The tectonic setting of the Sicily Channel is governed by two different geodynamic processes. While the NW sector of the channel is involved in the Maghrebian-Apennine orogeny, the central one is affected by the rift system that generated the Malta, Linosa and Pantelleria troughs. As a consequence, two deformation regimes coexist, namely a NW-SE oriented compression and a NE-SW oriented extension (Corti et al., 2006).

Analysis of multi- and single-channel seismic reflection profiles (from the VIDEPI database, industry and newly acquired high-resolution sparker profiles) in the NW Sicily channel has allowed to detail the structural pattern and has led to a tectonic reconstruction that refines existing models (Argnani et al., 1986; 1990; Antonelli, 1988; Civile et al., 2014).

Results confirm the known migration of the locus of active shortening from NW toward SE. In the NW, the Egadi thrust front is characterized by an intense Miocene deformation with a deep-seated thrust-ramp geometry, partly different from the thin-skinned model (Catalano, 1986; 1995; Antonelli et al., 1988; Roure et al., 2012; Civile et al., 2014). Seismic analysis showed that deactivation of the thrust system is broadly marked by a prominent high-amplitude reflector correlated with the onshore sandy member of the Terravecchia formation, roughly 8 Ma old (Basilone, 2012).

Younger contraction is transferred to the southeast on the eastern side of the Adventure Plateau, along the Adventure thrust front (ATF; Argnani et al., 1987; Antonelli et al., 1988). The structure shows evidence of inversion of an inherited Mesozoic crustal boundary between the Trapanese and Saccense domain, which in the Miocene marked the transition from the proximal shelf facies to the distal ramp facies in the Terravecchia foredeep. Activity of the ATF is bracketed between the latest Miocene and the early Miocene, and is broadly sealed by the top of Trubi formation (~3 Ma).

On land observations in the area of Castelvetrano highlight a gentle fold in the Quaternary deposits related to an anticline ramp (Barreca et al., 2014). Offshore, the prolongation of the Castelvetrano front is not linear, but is transferred *en-echelon* to a reverse fault just east of Capo Granitola. During the Plio-Pleistocene, the offshore between Capo Granitola and Sciacca is deformed by a N-S trending transcurrent belt with either normal or reverse component of motion. The border fault segments are arranged *en echelon* and the relative movement along the fault belt appears to be sinistral.

The Plio-Pleistocene contractional and strike-slip deformation is related to the oblique African-European, and accompanies, in the Egadi area, to transtensional re-activation of normal faults related to the rift system that in the early Pliocene crosscut Egadi thrust belt. In this sector, these last movements are associated to a new generation of distributed back-thrust reverse faults.

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Interaction between volcanism and extensional faulting in the Campania continental margin

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Keywords: volcanism, normal faults, sequence stratigraphy, Tyrrhenian Sea margin.

The interaction between extensional tectonics, magma chambers and volcanism controls the migration of magma in the crust and regulates the frequency, volume and location of volcanic eruptions. These extensional faults, because of their high permeability, can intercept the crustal magmatic bodies and are a preferential site of migration from the reservoir to the surface. They can control the location of central volcanoes, and induce asymmetrical basin subsidence and fissural explosive emission.

The Campania continental margin corresponds to Quaternary deep sedimentary basins located in a key area: the hinge between the Apennines fold-thrust belt and the Tyrrhenian Sea backarc basin. It results the ideal place to study the interaction between extensional tectonics and volcanism because it was characterized by active tectonics, several central volcanoes and large-volume ignimbrite eruptions. During the last two decades our research group investigated the link between tectonics and volcanism in the Campania margin and furnished a detailed chronostratigraphic framework based on a sequence stratigraphy analysis that integrated seismic reflection profiles and wireline logs. Besides visualisation in three dimensions has helped us interpret the stratigraphic and structural complexity of the study area. We reconstructed the geometry of the fault pattern and recognised and mapped several newly discovered volcanic edifices in the Gaeta and Naples bays. These volcanoes, spanning in age from lower to middle Pleistocene, are comparable in size to the edifices of Campi Flegrei and Vesuvius. Our 3D digital models of the subsurface show that several volcanic vents are located on faults, which is further evidence that an interplay between extensional faulting and volcanism in the Campania margin. On the other hand the evolution of volcano edifices are strictly controlled by the regional structural framework as the example of Vesuvius. The study area corresponds to a sediment overfilled/balanced infill basin type, and the analysis of the stratigraphic succession of the basins permit to reconstruct a detailed chronostratigraphic framework of the sedimentary, tectonics and volcanic events. The well data indicate that the Quaternary succession consists of offshore, shoreface and coal-bearing coastal plain deposits arranged to form thick aggradational and retrogradational units. The basin subsidence curve reveals a very rapid subsidence resulting from the superposition of rift episodes with cycles of some hundred thousand years. Based on the subsidence rates three stages were recognized during each rift episode, respectively a syn rift, a climax and a late rift. The stratigraphic analysis reveals a very rapid evolution of the multistage rift basins and allows to recognize the occurrence of the volcanic events at the beginning of the climax rift stages.

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Topography, river network and recent fault activity at the margins of the Central Main Ethiopian Rift (East Africa)

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Keywords: Main Ethiopian Rift, active tectonics, fluvial network, river longitudinal profiles, rifting evolution.

Along its length, the Main Ethiopian Rift (MER) in East Africa records a transition from early fault-dominated morphology in the South to axial magma assisted-rifting typical of continental break-up in the North. It is one of the few locations on Earth offering a complete picture of the evolution of continental rifting and thus provides a unique opportunity to directly analyze how the drainage network reorganize under extensional tectonic forcing. In this paper we present a new analysis of the river network and relative landforms —complemented with a summary of recent geological data— at both rift margins of the Central MER, a key sector of the rift capturing the phase of drainage reorganization between incipient and mature rifting. This analysis shows that hydrography is strongly influenced by recent tectonics. Rectangular drainage patterns, windgaps, and lacustrine/swampy areas formed by structural dams document that the rivers are in continuous competition with fault activity. The irregular longitudinal profiles (with knickpoints/knickzones in correspondence with faults) also suggest that rivers are in a transient state of disequilibrium related to recent tectonic activity at rift margins, in agreement with previous geological and seismological data. A more regional analysis extended to the adjoining Northern and Southern MER indicates that rifting evolves from initial stages characterized by margins poorly incised by rivers with gentle channel gradients (except in correspondence with faults), to mature phases in which rift margins are highly incised by a well organized fluvial network composed by concave and steep rivers. Our regional analysis also indicates a stronger and/or more recent tectonic activity at the rift margins proceeding to the south, in line with previous models of rift development.

Contrasting exhumation and deformation style along a rift shoulder: insights from the Transantarctic Mountains

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Keywords: Continental rift, rift shoulder uplift, Transantarctic Mountain, Antarctica.

The Transantarctic Mountains (TAM) are one of the most enigmatic topographic feature around the world growth in response to the extensional tectonics only. The TAM mark the boundary between the East Antarctic craton and the thinned crust of the West Antarctic Rift System one of the largest continental rift domain on Earth, started in the Mesozoic, and considered still active today (Storti et al., 2009; Rossetti et al., 2006). Cenozoic morphotectonic evolution and present day elevation of the TAM have been interpreted as rift shoulder uplift due to lithospheric break along the transition from thick cratonic crust and young thin crust (Van deer Beek et al., 1994). On the other hand, recent tomographic models have shown a contribution of the mantle upwelling in sustaining the present topography and controlling volcanism (Faccenna et al., 2012).

Here we present a thermochronological study coupled with structural field data focused in two key areas for the investigation of the deep processes that cause the crustal deformation. The Admiralty Mountains form the northern tip of the TAM, and they are different from the rest of the chain for the extent of the uplifted area, the total amount of exhumation, and the alpine-style morphological feature. Preliminary thermochronological data of samples collected during 2014-2015 Antarctic expedition, show ages that range between 26.5±2.2 and 65.9±3.5 Ma suggesting a rapid phase around 26 Ma.

The Royal Society Range is located in the South Victoria Land, near to McMurdo volcanoes. The topography is elevated up to 4000 m but characterized by a flat summit with the remnant of a paleo erosional surface. Thermochronological data suggest that the surface has been uplifted of about 1 km with respect to the adjacent region (Fitzgerald, 1992), but the total amount of exhumation and length-wave of the vertical deformation are minor with respect to the Admiralty Mts.

The comparison of the exhumation pattern, faults arrangements, and volcanic evolution suggest two contrasting origins for the present topography along the rift shoulder: a mantle flow and a lithospheric flexural rebound.

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Plio-Quaternary tectono-stratigraphic evolution of the Paola fore-arc basin (western Calabria continental margin): Insight from high-resolution seismic reflection data

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Keywords: Calabrian Arc, Ionian subduction system, Tyrrhenian back arc basin.

We reconstructed the most relevant geologic features across the Paola Basin (offshore western Calabria) and its Pliocene to Recent sedimentary and tectonic evolution using a grid of seismic profiles acquired within the frame of the EU-SINBUS project in the 1995. We used seismostratigraphic analysis to outline the seismic units. The Messinian horizon, as well as regional unconformities recognized in the Plio-Pleistocene geological record of the basins developed within or adjacent to the Calabrian Arc, played a key role to assign ages to the sedimentary units. We identified five seismic units on seismic lines, based on the internal configuration and seismic-stratigraphic character of reflectors (amplitude, reflection continuity, external shape, and frequency). Moving from the Calabria coast-line to the west, the Paola Basin can be partitioned into two sectors characterized by different Plio-Quaternary tectonic deformation separated by a NNW-SSE elongated area that coincides with the basin depocenter. Plio-Quaternary high-angle, reverse faults are widely spread over the western sector of the basin that correspond to an arcuate ridge separating the basin from the Marsili abyssal plain. A high-angle, NNE-trending, normal fault system, on the contrary, developed on the south-west tip of the basin only, where the fault offset deforms the Messinian horizon of ca. 500 m. Data suggest that limited vertical slip occurs along reverse faults detected at the border and inside the sedimentary infilling of the Paola Basin, reaching thickness of more than 3.8s two way travel time. A series of acoustically opaque cone-shaped zones on the western flanks of the basin interrupts the continuity of the sequences. These zones, 2 km-wide, propagate to the surface intruding the lower sequence and folding both the sedimentary layering of the upper sequence and the sea-floor. The features correspond to intruded and erupted mud diapirs that pierce the entire sequence because of the occurrence of overpressured fluids escaping to the surface via any permeable horizons and tectonic structures. The sequences reflection pattern can be interpreted as the result of the infilling of thrust-top basin related to a prograding system located between a growth ramp-anticline to the west and a culmination of basement-thrust sheets to the East, activated in the context of the Tyrrhenian Sea opening and lateral escape of the Calabrian block. Thus, mechanisms for subsidence affecting this area since the Late Neogene significantly differ from extensional and/or compressional processes responsible for formation of basins along the Sardinia and northern Sicily continental margins. Taking into account the pattern of the sedimentary infilling, the basin shape and its position in the regional context, we propose that the Paola Basin developed near the northern edge of the Ionian slab where tearing of the lithosphere is expected.

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Rifting kinematics along the Arabian Margin, Red Sea

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Keywords: Rift, Kinematics, Red Sea.

The Red Sea represents a young basin floored by oceanic, transitional, or thinned continental crust that formed between Africa and Arabia. According to most authors (e.g., Bosworth et al., 2005), rifting between Nubia and Arabia started in the late Oligocene (~27 Ma) and it is still in progress in the northern part of the Red Sea at latitudes greater than 24°N. Conversely, the area south of ~20.3°N displays a linear spreading ridge extending as south as 14.8°N, which formed in the early Pliocene (the first pulse of sea floor spreading occurred during chron C3n.2n, ~4.62 Ma, Schettino et al., 2016).

A transition zone (between 24°N and 20.3°N, present–day coordinates) exists between the northern and the southern sectors, characterized by a segmented spreading center that started forming at ~2.58 Ma (chron 2A, late Pliocene) in the southernmost area and propagated northwards. Some authors suggest that the present–day NE–SW spreading directions can be extended back to the early Miocene (ArRajehi et al., 2010). However, we are going to show, on the basis of geological evidence from the Arabian margin, that at least two phases of rifting, characterized by distinct extension directions, are necessary to explain the observed structural pattern of deformation in a wide area extending from 28°N to 20°N.

At present, there is no magnetic evidence for the existence of a linear spreading center in the northern Red Sea at latitudes higher than ~24°N. In this area, the syn–rift pattern of deformation along the Arabian margin is only partly coherent with the present day NE–SW sea floor spreading directions and with the observed trend of fracture zones in the Red Sea. In fact, an older set of rift structures was found during a field trip performed along the northern and central Red Sea Arabian margin (March-April 2015), suggesting the existence of an earlier rifting stage characterized by N–S trending strike–slip faults and E–W normal faults.

The objective of this field trip was to investigate the hypothesis that an early phase of N–S extension and formation of left–lateral pull–apart basins characterized the separation of Arabia from Nubia, as suggested by Makris and Rihm (1991) and Ghebreab (1998) and by a preliminary analysis of remote sensing data. The necessity of performing structural observations along a wide area along the eastern margin of the northern and central Red Sea led us to select 12 sites where the preliminary morpho–structural analysis of ASTER–GDEM data and geological maps suggested the possibility to study the overprint of younger NE–SW structures on pre–existing N–S strike–slip faults.

For each survey site, a number of stations were established to measure kinematic indicators. Most of the mapped structures are E–W and NW-SE normal faults or N–S and NE-SW high–angle strike–slip faults. These different faults belong to the older N-S/E-W system and the younger NW–SE/NE–SW system. Field evidence shows that the second system cuts the first one.

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Post-rift compression along the Red Sea margin of Arabia

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Keywords: Rift, Basin inversion, Red Sea.

Post-rift compression along passive margins is an interesting phenomenon that has been observed both in the central-northen Atlantic region and along the Red Sea margins.

It has been associated either with small-scale upper mantle convection (Ligi et al., 2012) or transient non-linear viscoelastic relaxation at the onset of sea-floor spreading (Schettino and Ranalli, this volume).

Here we report on a geological survey performed along the Saudi Arabian margin, devoted to the discovery of basin inversion structures at the termination of continent-continent fracture zones (Schettino et al., 2015).

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Schettino A., Macchiavelli C., Pierantoni P.P., Zanoni, D. & Rasul N. 2016. Recent kinematics of the tectonic plates surrounding the Red Sea and Gulf of Aden, Geophys. J. Int., in review.

The evolution of the Buia basin (Eritrea): inferences on the northern tip of Afar triangle

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Keywords: Afar, extensional tectonics, basin evolution.

The Afar region is a wide triangular area of lowlands located at the triple junction between the African, Somalia, and Arabian plates, which are currently diverging at different rates.

The connection between the Afar region and the western Ethiopian and southern Somalian plateaus is realised through well-developed normal fault systems. The western transition occurs through roughly N-S trending faults, whereas the southern border faults display a roughly E-W trend. Currently, the extension vector is roughly oriented in a NE-SW direction in the Afar, Red Sea and Gulf of Aden, in respect to Arabia plate, whereas south of the Tendaho–Goba'ad discontinuity the Nubian–Somalian divergence, evidenced by the Main Ethiopian Rift (MER), is approximately N95-100°E.

This study focuses on the tectono-sedimentary evolution of the continental Early-Middle Pleistocene Buia Basin, located at the northern tip of the Afar region, 110 km south of Massawa, and filled with 500-600 m thick fluvio-lacustrine deposits bearing *Homo erectus* remains. The N-S trending border normal faults delimiting the Ethiopian plateau also controlled the evolution of the basin. Moreover, these faults interfere with the NW-NNW trending normal faults and volcanic alignments of the Afar system. These latter represent the northern prosecution of the alignment that from Erta-Ale volcano ends up in the proximity of Red Sea with Alid and Jalua volcanoes.

The reconstructed stratigraphy of the Buia basin includes six formations, from bottom up: Bukra Fm., Alat Fm., Wara Fm., Goreya Fm., Aro Fm. and Addai Fm. Sedimentation occurred mainly along the basin axis and allowed accumulation of sand and mud deposits with subordinate gravels close to the basin margin. The age of the basin-fill succession is well constrained through integration between paleomagnetic, geochronological and paleontological data.

The Buia basin is controlled by two main roughly NNW-SSE trending, east dipping normal faults. The westernmost fault delimits the basins from the plateau, whereas the easternmost marks the limit between the basin succession and the Late Pleistocene Samoti Plain. Moreover, the succession is affected by many small faults that can be grouped into different systems based on their orientation. The two most represented fault systems are generally NE–SW and NW-SE oriented, and are either synthetic or antithetic in relation to the two major east-dipping faults, whereas minor systems are N-S and E-W oriented. In general, the vertical throw of these faults does not exceed few tens of meters, and only locally NE-SW trending faults show higher displacement of about 100 m.

The timing of deformation is well constrained by the age of syntectonic sediments and volcanics as well as by crosscutting relations among structures. These relations allowed us to refine the timing of deformation of this sector of Afar in the frame of the geodynamical evolution of the three major plates of the area.

Plate motions around the Red Sea since the Early Oligocene

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Keywords: Magnetic anomalies: modelling and interpretation, Marine magnetics and palaeomagnetics.

The Red Sea and Gulf of Aden represent two young basins that formed between Africa and Arabia since the early Oligocene, floored by oceanic crust or by transitional and thinned continental crust. While in the easternmost Gulf of Aden the rift–drift transition can be dated chron C6 (~20.1 Ma), here we show that in the Red Sea the first pulse of sea floor spreading occurred during chron C3n.2n (~4.6 Ma) around ~17.1°N (present–day coordinates) and propagated southwards from this location, separating the Danakil microplate from Arabia. It is also shown that sea floor spreading between Arabia and Nubia started later, around chron 2A (~2.58 Ma), and propagated northwards. At present, there is no magnetic evidence for the existence of a linear spreading center in the northern Red Sea at latitudes higher than ~24°N and in the southern Red Sea below ~14.8°N. The present–day plate kinematics of this region can be described with high accuracy by a network of five interacting plates (Nubia, Arabia, Somalia, Sinai, and Danakil) and six triple junctions. For times older than anomaly 2A (~2.58 Ma) and up to anomaly 3, the absence of marine magnetic anomalies between Arabia and Nubia prevents a rigorous kinematic description of the five–plates system. However, there is strong evidence that the unique changes in plate motions since the early Miocene were a dramatic slowdown at chron C2 (~1.77 Ma) in the spreading or extension rates along the ridge and rift axes, thereby a good representation of the real plate motions can be obtained anyway by backward extension of the oldest Arabia – Nubia and Arabia – Danakil stage rotations determined on the basis of marine magnetic anomalies, respectively C2 – C2A and C2A – C3. In order to reconstruct the plate motions for times older than 4.6 Ma, we compiled a Moho grid for the Red Sea region and perfomed a balancing of 23 crustal cross–sections across the central and northern Red Sea. This technique allowed to determine strain rates and to establish that the main rifting phase started at ~27 Ma and proceeded at constant velocity until today. We also found that the Sinai and Danakil plates formed at ~14 Ma, while a proto–rifting stage between 30 and 27 Ma, characterized by N–S strike–slip kinematics, could be necessary to explain the observed pattern of syn–rift faults.

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A geodynamic model for fast sea floor spreading episodes in the Red Sea

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Keywords: geodynamics, Red Sea.

An analysis performed on 68 magnetic profiles from the Red Sea reveals the existence of a pair of conjugate lineations having age C3n.1r (4.29 Ma), located very close to isochrons 3. These are the oldest magnetic lineations identified in this region. They suggest an initial short pulse of fast or ultra–fast spreading in the southern Red Sea, similar to that observed in the northern region by Ligi et al. (2011), but at a much larger scale (~200 km). Here we propose a rheological explanation of this phenomenon, which may provide some important insights into the rifting process. The model assumes that in the rifting process the extended continental margins accumulate some amount of elastic strain, which cannot be released seismically. After the onset of sea–floor spreading, a phase of transient creep allows the release of the accumulated strain energy through non–linear anelastic relaxation. Then, the conjugated margins are subject to post–rift contraction and eventually to tectonic inversion of the rift structures, because an extra space is created along the spreading ridge as a consequence of rapid transient contraction of the conjugate margins. We show that this process can be described by a non–linear Kelvin model, characterized by a power–law rheology of the viscous component. Although this model suggests that the characteristic transient time for this process is of the order of 10^4 yr, geological data obtained during two research expeditions along the western Arabian margin show that post–rift inversion is still in progress in the central Red Sea area, where the oldest oceanic crust has age 2.58 Ma. Therefore, it is suggested that relaxation if confined within small chunks of the continental margins and that the deformation gradually propagates inland.

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Unravelling the evolution of a rift margin affected by non-coaxial phases of extension: a case study from the Utsira High and Stord Basin (North Sea - Norway)

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Keywords: North Sea, Stord Basin, Seismic interpretation, normal faults, fault reactivation.

In several rift basins, faults exhibit different orientation and often are oblique to the main rift margins.

This characteristic is common in rifts where separate basins overlap in a triple junction area with single arms developed in response to local stress fields that are different with respect to the adjoining basins (e.g., the North Sea and East African rift). In this case, the configuration of the distinct rift arm margins is complicated due to the superposition of, sometimes diachronous, extensional events and is more difficult to unravel the paleo-stress fields.

The Viking Graben forms the north-western arm of the North Sea rift. Along this broadly straight NNE-SSW trending basin, several arrays of normal faults with different orientation were active along the basin margins during the late Paleozoic-Mesozoic times. In particular, several authors emphasized a multiphase rift with different direction of extension and others invoke an inherited control exerted by the pre-existing basement discontinuities (Færseth, 1996; Duffy et al., 2015).

In the Norway offshore, the Utsira High and the Stord Basin are two Mesozoic paleo-domains interposed between the central Viking Graben depocenter and the Norwegian coastline. The area was affected by different fault arrays trending N-S, NNE-SSW, NE-SW and NW-SE with several evidences of multiple reactivation during the Mesozoic. In this study we interpreted a post-stack time-migrated 3D seismic reflection cube tied to exploration well data in order to define the fault network and to reconstruct the structural evolution of key-areas. Moreover, seismic attributes were extracted from seismic data with the aim to unravel the abutting relationships between faults and to define the relative chronology of the fault network. The assessment of potential reactivation of weakness zones within basement and perturbation in the local stress field around pre-existing discontinuities have been performed by slip tendency analysis and Coulomb software.

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A Pyrenean mid-Cretaceous extensional fault system in the Briançonnais Domain of the Alps: implications for the eastern termination of the segmented Bay of Biscay-Pyrenean rift system

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Keywords: mid-Cretaceous, Briançonnais Domain, Bay of Biscay-Pyrenean rift system.

In the Briançonnais domain of the Ligurian Alps, Digital Elevation Model, orthophotos, and geological maps have been integrated with field observations and subsurface data from the karst network, in order to reconstruct the 3D structure of a crustal-scale mid-Cretaceous extensional fault system. This is made by a major E-W striking fault that has in its northern block a set of E-dipping transverse extensional faults. The master fault has been reactivated as a strike-slip structure during the alpine deformation and its original geometry, including fault dip and cutoff angles, is no longer recognisable. Conversely, the E-dipping faults and the fault-bounded blocks almost completely preserve their Cretaceous geometry. The alpine deformation has poorly modified these transverse faults, which affect a Mesozoic sedimentary sequence and the underlying Paleozoic basement with extensional displacements in the order of many hundreds of meters.

Removing the about 120° counter-clockwise vertical axis rotation associated with the alpine orogeny, leads the E-dipping fault to become about SSW-dipping, while the master fault becomes almost parallel to a suite of NNE-SSW to NE-SW striking faults, namely the Cérvennes, Nimes, and Durance-Aix faults, that connect the eastern portion of the Pyrenean mountain range to the north-verging thrust system of the Provence region, in the foreland of the western Alps. These faults, which have been inherited from the extensional stage associated with the opening of the Alpine Tethys, were delimiting to the east the Bay of Biscay - Pyrenean rift system during the mid-Cretaceous separation of Iberia from Eurasia. We propose that the mid-Cretaceous extensional fault system described here represented part of such a NNE-SSW striking transfer zone, likely ensuring the connection between the Pyrenean arm of the Bay of Biscay - Pyrenean rift system and a further eastern arm, which was involving tethyan domains

SESSION S21

The International Map Year: new technologies, perspectives and outlook of geological mapping and outcrop visualization

CONVENERS AND CHAIRPERSONS

Chiara D'Ambrogi (Servizio Geologico d'Italia - ISPRA)
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Degree of fabric evolution and metamorphic transformation in metamorphic basements: the map of Lago della Vecchia – Valle d'Irogna area, Sesia Lanzo Zone, Western Alps

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Keywords: Multiscale analysis, petro-structural mapping, fabric evolution, metamorphic transformation.

The Lago della Vecchia-Valle Irogna (upper Cervo valley, Biella) rocks belong to the Eclogitic Micaschists Complex of the Sesia-Lanzo Zone, within the Western Alps that underwent high pressure (HP) metamorphism during the Alpine subduction. The area consists of metaintrusives, minor country rocks (micaschists and banded gneisses) and metabasic boudins and lenses. The multiscale analysis reveals seven groups of superimposed structures: a pre-Alpine magmatic stage (M0), five Alpine deformation episodes (D1 to D5) followed by a second magmatic stage (M6). D1 to D5 structures mainly consist of folds, foliations and shear zones. The integration of meso and microstructural analysis allowed reconstructing the sequence of superposed structural and metamorphic stages. M0 relicts consist of igneous textures and minerals preserved as low-strain lenses within tectonitic and mylonitic metaintrusives. S1 foliation (D1) developed under eclogitic facies conditions and is better recorded in eclogitic boudins; S2 foliation (D2) is the most pervasive fabric in the area and developed under epidote-blueschist facies conditions, whereas D3 and D4 consist of localised shear zones and open folds marked by greenschist facies assemblages. D5 consists of km-long cataclastic-mylonitic shear zones developed under greenschist facies conditions. M6 stage is represented by the intrusion of andesitic dikes that postdate all the previous fabrics. The superposed structures are represented in the objective (solid) and interpretative (drift) maps, both at a 1:10,000 scale, and two cross-sections. The correlation of fabric evolution and metamorphic transformation for the penetrative evolution stage (D2) is showed in fabric (FE) and metamorphic (MT) evolution thematic maps at a 1:10,000 scale, which integrate mesoscale observations, bulk rock chemical systems, relative chronology of metamorphic assemblages inferred by microstructural analysis and qualitative and quantitative thermo-barometric estimates.

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The new geological map of the area between Mendrisio (Switzerland), Como and Varese: 300 million years of geological history

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Keywords: Geological map, Southern Alps, Lombardy.

The new sheet Mendrisio of the Swiss Geological Atlas of Switzerland 1:25 000 covers an area that is crucial for the understanding of the sedimentary and tectonic history of the western Southern Alps of Lombardy (northern Italy) and Ticino (Switzerland). Three major tectono-stratigraphic units can be distinguished: 1. the area of Monte San Giorgio that is exposing a stratigraphic succession from the Hercynian basement to the Cretaceous Flysch Lombardo and is characterized by a Mesozoic high; 2. the Generoso area, separated from the Monte San Giorgio area by a Liassic syn-sedimentary listric fault of several kilometres throw and dominated by 4 km basinal syn-rift (Lower Liassic) and post-rift (Middle Liassic–Cretaceous) sediments, and 3. the unit of the Gonfolite Lombarda Group, an Oligo–Miocene clastic wedge that was back-thrusted onto the Mesozoic successions in late Miocene times. The map documents the evolutionary steps from Permian transtension and volcanism, Triassic basin formation accompanied by the deposition of hydrocarbon source rocks, late Triassic to middle Liassic rifting along syn-sedimentary crustal faults, and ocean-wide palaeo-oceanographic changes during post-rift thermal subsidence. Early Alpine pre-collisional orogenic movements are testified to by late Cretaceous flysch sediments; Oligo–Miocene post-collisional ones by the deep-water clastic wedge of the Gonfolite Lombarda Group that is part of the subsurface Milano fold belt below the Po Plain. Deep valleys, incised into the fold belt and flooded by the early Pliocene transgression are related to the Messinian salinity crisis of the Mediterranean.

Four major Quaternary chronostratigraphic units are distinguished from top to bottom:

4. Postglacial deposits ("*Depositi del Postglaciale*"; 0–0.0117 Ma) are referred entirely to the Holocene. 3. Deposits of the Last Glacial Maximum and the Late-glacial ("*Depositi dell'Ultimo Massimo Glaciale e del Tardoglaciale*"; 0.0117–0.029 Ma). 2. Deposits preceding the Last Glacial Maximum ("*Depositi precedenti all'Ultimo Massimo Glaciale*"; 0.029–0.781 Ma), both referred to the Middle and Late Pleistocene. 1. Deposits referred to the Early Pleistocene ("*Depositi del Pleistocene inferiore*"; 0.781–2.588 Ma).

In the legend of the map, we represent both age and facies of the Quaternary deposits. This representation of the chronostratigraphical units enables a 'harmonised cartography' in a larger regional framework because it allows for a quick visualisation of the spatial extent of the main morphoclimatic events, as, for example, the maximal glacial extent during the Last Glaciation compared to the previous ones. It also facilitates the understanding of the dynamics and the recognition of the main glacial flow directions in the area, in particular of the important role played by the Larian lobe of the Adda glacier with respect to the glacial lobes of Lake Lugano.

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EMODnet Geology: a European Project of harmonized digital cartography of submerged areas

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Keywords: digital cartography, submerged areas, geological mapping, harmonization.

Marine geological mapping is largely based on acquisition of remote sensing data. Multibeam and sidescan sonar provide continuous representation of acoustic facies on the seafloor for both geomorphology and seabed constitution, after groundtruthing. Other methods of acquisition (seismics, samplings, scuba diving surveys) only provide discontinuous data. However, these latter allow for groundtruthing as well as for sub-bottom information. This is the approach adopted by the Geological Survey of Italy for the geological mapping of submerged areas in the frame of the Italian Mapping Project (CARG, http://www.isprambiente.gov.it/Media/carg/index.html). Moreover, a database collecting all kind of information has been developed. Digital cartography is useful to gather homogeneous data, subdivided into different layers which can be correlated and compared allowing further interpretation.

The European Marine Observation and Data Network (EMODNet, http://www.emodnet.eu/geology) Project aims at the collection of as many existing data as possible on European Seas to be represented on digital maps at the 1:250,000 scale, accessible via web through a dedicated portal. It is articulated into different Lots concerning Bathymetry, Geology, Biology, Chemistry, Physics, Physical Habitats, Human activities.

The Geology Lot is realized by a Consortium in which the Geological Survey of Italy is partner. In order to deliver the products requested, data deriving from the CARG Project are complemented by additional information obtained from the literature as well as by expert interpretation of available data.

EMODnet Geology requires the compilation of a number of layers subdivided into Work Packages (WP), referring to seafloor sediments grainsize, sedimentation rates, Quaternary geology, pre-Quaternary geology and stratigraphy, coastal behaviour, geological events (earthquakes, volcanoes, landslides), mineral resources. The Geological Survey of Italy is WP Leader for geological events and, in agreement with other partners, has included tsunamis, tectonics and fluid emissions among the features to be represented.

This Project offered the opportunity to integrate, compare and cross-check a lot of different data from various sources obtaining new thematic maps. The same might be done among the different Lots aimed at a better integration of all the disciplines.

Continuous monitoring Aeolian activity in Herschel Crater, Mars

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Keywords: Large Dark Dunes, Aeolian Processes, Herschel Crater.

Herschel Crater is a 300km- diameter impact basin located close to the Martian equator (14.4°S, 130°E), where aeolian activity was already characterized by Cardinale et al. (2016) which demonstrated that Herschel dunes are active under the current atmospheric wind conditions.

In this work, we performed further analysis on the migration of the aeolian bedforms and we detected active sand motion in another dune field located in the east area of Herschel Crater.

We quantified the movement of ripple and dunes using a greater number of HiRISE data set (McEwen et al., 2007) than the first analysis (Cardinale et al., 2016). We detected that dune and ripple are mainly shaped by prevailing winds coming from the north during a time span of 7 years. However, the complex pattern of the ripples indicate the interaction of diverse wind flows within the dune field.

These first analyses are in agreement with the previously detected Aeolian activity (Cardinale et al., 2016) in Herschel Crater and demonstrate that the surface aeolian features are still active under the current atmospheric wind conditions.

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McEwen, A. S., et al. (2007), Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE), J. Geophys. Res., 112, E05S02, doi: 10.1029/2005JE002605.

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Application of the Matheson test implemented in a GIS environment: the Ventotene case study (Latium, Italy)

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Keywords: susceptibility, landslide, Ventotene, Matheson.

Ventotene island is located in the eastern part of the Pontine Archipelago (Latium, Italy).

Ventotene represents the south-eastern flank of a strato-volcano formed by the superimposition of deposits ejected during both effusive and explosive eruptions, over the last 800.000 years of activity.

As regards lithology, the Ventotene island may be subdivided into three sector: a lower part, mostly formed of lava deposits, which reaches its maximum thickness at the southern end of the island, at Capo Arco; an intermediate part, mostly pyroclastic, which forms the central part of the island, overlying the lava series; finally, the upper part, which forms the northern sector of the island, represented by reworked volcanic materials. The whole succession dips toward the NE, with its maximum thickness at Capo Arco, and its minimum at the level of the inhabited part of Ventotene.

From a morphological standpoint, the island is characterized by the presence of a slightly dipping plateau, bordered by cliffs with height ranging between 130 m (in the southern sector) and 10 m (in the northern sector). The plateau surface is grooved with flat-bottomed valleys, formed along some the principal of the underlying tuff.

The island is affected by a continuous activity of erosional and mass instability processes, caused by exogenous agents (sea wave action, wind abrasion and erosion due to runoff and infiltration water), that are at the origin of a long sequence of erosion and landslides.

Even the island geological setup, the rock slide occur mostly along the entire perimeter of the island, in the tuff formation with fall, toppling and sliding mechanisms.The progressive evolution of the cliffs through such processes is heavily reducing the size of the island, at the same time threatening and causing damage to the precious cultural heritage of the Roman era.

Considering the high coastal landslide risk and scarce economic resources, it is necessary to define automated procedures which, beginning with field data collected in sample areas, might identify area of highest risk.

This article will, therefore, propose a quantitative method for the analysis of landslides based on the application of the Matheson test, implemented in a GIS environment. More specifically, we have developed a computational algorithm based on geomechanical surveys, carried out on different areas of the island for commercial purposes, and considering four failure mechanisms (planar sliding, wedge slip, flexural tipping and tilting block), which have enabled the elaboration of a landslide hazard map in stone formations of tuff cliffs on the island of Ventotene.

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The Mesozoic of the southern Amerini Mts. (Central Apennines, Italy): new insights from field-mapping and facies analysis

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Keywords: Geological mapping, Umbria-Marche-Sabina Succession, Mesozoic paleogeography, Early Cretaceous tectonic.

New stratigraphic-structural data are presented herein from the Amelia Ridge (Central Apennines, Italy), which is characterized by Meso-Cenozoic rocks of the Umbria-Marche-Sabina sedimentary succession. The region experienced a rifting phase during the Early Jurassic, when the vast Hettangian Calcare Massiccio carbonate platform was dismembered by normal faults, causing a complex morpho-structural patchwork of uplifted and downthrown blocks. Drowning of the benthic factories led to the development of two main sedimentary environments: pelagic carbonate platforms (PCPs) and basins. The Early Jurassic rift architecture is documented by facies and thickness variations of the Jurassic-Lower Cretaceous post-rift succession.

In the southern Amerini Mts., a geological mapping project on the 1:10.000 or locally 1:5.000 scale, coupled with facies analysis and a dense network of stratigraphic/sedimentologic logs, resulted in the identification of several Jurassic structural highs (Amelia, Fornole and Foce sectors), flanked by deeper-water basins. Although the PCP-top successions are not exposed due to post-Jurassic faulting and modern erosion, highly distinctive facies associations define the escarpment margins of these platforms and the adjacent hangingwall-block successions that onlap them, which often embed gravity-driven deposits including rock-fall megaclastics. Fine-grained calcarenites made of shallow water-derived material are found embedded in the upper Pliensbachian-Bajocian part of the basin-fill succession in the eastern sector of the study area. This occurrence is unexpected as these deposits postdate the drowning of the local Calcare Massiccio carbonate platform, which suggests provenance from the Latium-Abruzzi Platform. This provides new evidence for restoring the Jurassic paleogeography of Central Apennines, and for deciphering the itineraries of resedimented carbonate sands from this relatively distant source-area.

Evidence for an Early Cretaceous extensional tectonic phase, which is well-documented in the neighbouring Narni Ridge, has now been also recognized in the Amelia area. Here the Marne a Fucoidi Fm. (Aptian-Albian) rests unconformably on the Hettangian shallow-water carbonates of the Calcare Massiccio Fm., as a result of rejuvenation and erosion of the Early Jurassic margin of the Amelia intra-basinal high.

Following Neogene Apenninic shortening, the region was extended in the Pliocene-Quaternary. Within this picture of polyphase deformation, the role played by Mesozoic inherited structures and by large (hill-size) olistoliths in our study area is also discussed.

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Geo-petrological mapping of granitoid rocks along the Molochio-Antonimina tectonic alignment (southern Calabria) via Kriging interpolation technique

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Keywords: Kriging, Interpolation, Granitoids, GIS.

Reliability of geological mapping of granitoid complexes depends on the integration between field mapping techniques and laboratory investigations. Mapping based on rock structures and mineral compositions not always allows the distribution of all the rock types cropping out in a given area to be depicted in detail.

In this view, we applied for the first time an automated GIS-based classification of granitoid rocks based on the construction of interpolated maps of some key geochemical indicators, able to show significant differences between rocks apparently very similar to each other.

Study area is located at the boundary between the Aspromonte and Serre Massifs, along a hypothetical tectonic alignment running between the Molochio and Antonimina villages, in order to verify the existence of a possible regional scale strike-slip fault separating the nappe-like edifice of the Aspromonte Massif from the well preserved Variscan crustal section of the Serre Massif.

Geological-structural survey showed that the granitoids to the north of the alignment are intruded into low-grade metamorphic rocks, while the granitoids to the south are intruded into a migmatitic complex.

In order to verify the possibility of identifying the two different crustal domains also in areas with no visible intrusive contacts with the wall rocks, 35(?) granitoid samples were investigated in their basic petrographic and geochemical features. Geochemical data were then used to derive a number of interpolation maps via kriging technique of some key geochemical indicators. Kriging interpolation was here used because it allows the variability of a numeric parameter, such as the chemical element concentration, to be correlated to the distance between the various samples, weighting at the same time the error derived from the differential distance from each of the investigated samples.

Several “prediction maps” were finally produced, allowing the different rock types, as well a as their specific geochemical characteristics, to be portrayed, also beneath sediment covers. “Error maps”, estimating the amount of potential output errors, were also obtained.

Among all the interpolated geochemical parameters, SiO2, P2O5, K2O, the MALI index and the Al2O3/TiO2 ratio resulted to be the most informative.

The final geo-petrological map was then produced following the INSPIRE directives (INfrastructure for SPatial Information in Europe), aimed to promote the adoption of an interoperable spatial data infrastructure as that proposed by the North American Geological Survey, which is in turn inspired to GeoSciML-like conceptual model.

The distribution study of these parameters highlighted the occurrence of different geospatial trends to the north and to the south of the potential tectonic alignment confirming field evidences, such as the presence of sub-vertical foliated gouges, consistent with the surficial reactivation of a possibly regional-scale strike-slip tectonics.

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A gateway to the subsurface: 3D geological models and derived maps through internet

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Keywords: Subsurface, 3D modelling, maps, WMS services, metadata.

The advent of the digital era has driven the geoscientific community to develop and use techniques and tools for data storage, management, and 3D modelling. These techniques have strongly addressed the use of surface data and their optimization as geometrical constraints, while almost only the O&G industry has investigated problems related to data management, integration and 3D modelling in areas without any support from the outcrop (e.g. large plains, intermountain basins, offshore areas).

We designed a workflow for 3D modelling building based mainly on the interpretation of subsurface data (i.e. seismic lines, well logs), their time-depth conversion, the validation of the interpretation consistency with independent analysis (e.g. a high pass filtered Bouguer anomaly map), and including also the evaluation of the uncertainties.

The workflow has been fully tested in a wide flat area (5,700 km2) located in the central part of the Po Basin (Italian pilot area of the EU funded GeoMol Project; www.geomol.eu); the resulting 3D geological model includes patches representing 15 horizons, from Triassic up to Pleistocene, and different fault systems (e.g. inherited normal faults, thrusts with two different decollement levels, and minor faults).

This comprehensive 3D geological model allows to visualize, in detail, stratigraphic and structural elements at depth, but it is not easy to handle for not-specialists; on the contrary geological maps still remain the most widely understandable and workable geological products. For this reason we produced several 3D model-derived maps to facilitate the use of the information: an isobath map for each horizon, and geological maps at predefined depth (e.g. geology at depth of 3,000 m).

In order to maintain a high level of information, the limitations that are inherent in the traditional geological maps have been overcome with new style of bi-dimensional rendering, especially for the complex architecture of stacking thrust systems: the faults are represented in map as the projection of the fault plane between the upper tip and the hangingwall cutoff of the mapped horizon.

Moreover the maps contain additional information: i) not occurrence of the horizon, ii) areas where the modelling is not possible with the available data, iii) distribution of the constraints, iv) data density.

For the first time 3D comprehensive geological models and derived subsurface maps are accessible through public web map services (WMS) on a dedicated Configurable MapViewer of the Geological Survey of Italy (GeoIT3D – 3D model-derived maps of the Italian subsurface: http://sgi2.isprambiente.it/GeoIT3D/), and with standard metadata in compliance with the INSPIRE Directive.

The Configurable MapViewer - CMV (a community-supported open source mapping framework built with the Esri JavaScript API and the Dojo Toolkit) allows to use a set of widgets for accessing data, including a query builder. A specific tool will be activated for viewing metadata.

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Nappe stacking and metamorphic evolution in the Western Tauern Window

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Keywords: Tauern Window, CARG project, Metamorphic Evolution.

The western Tauern Window is a key area for the reconstruction of the tectonic evolution of the Eastern Alps. Here basement units derived from the European margin are stacked together with their parautochthonous post-Variscan cover in a south-vergent crustal scale duplex that also involves the Glockner nappe (calcschists and ophiolites derived from the Penninic ocean).

The major lithostratigraphic units comprise: i) a polymetamorphic basement consisting of mainly amphibolites, migmatites, orthogneisses, and locally pre-Mesozoic ultramafic to mafic bodies; ii) the Tux and Zillertal orthogneiss (part of the "Zentralgneiss Auct.") that intruded unit (i) during early Permian times; iii) the parautochthonous metasedimentary cover including meta-conglomerates, calcitic and dolomitic marbles, calcareous micaschists, quartzites, and subordinate greenschists. iv) the Glockner Nappe, it consists of km-thick sequences of calcschists with interbeddings of prasinites, amphibolites and ultramafic bodies.

Along the tectonic contact between the northern and southern duplex antiforms a slice (about 1km-thick, wedging out westward) of graphite-rich garnet micaschists with minor quartzites and calcschists ("Greiner schists" Auct.) occurs.

Two phases of roughly coaxial isoclinal folding, the first one of these responsible for the regional foliation, have been recognized in the post-Variscan cover of the "Zentralgneiss". A pronounced stretching lineation, parallel to fold axes and ascribed to a strong flattening is well developed in quartz-rich rocks.

An amphibolite facies metamorphic stage characterized by static recrystallization of micas, garnet and amphibole ("Garbenschiefer" Auct.) is well recognizable in the post-Variscan metasedimentary units whereas its occurrence remains controversial in the Glockner nappe. This point still need to be resolved as the formation of the regional scale duplex, involving all described unit, is generally interpreted to had predated the static crystallization ("Tauercristallisation" Auct.). Late stage doming of the duplex, associated to folding at the mesoscale, caused eventually the present day structure with the two antiformal Tux and Zillertal domes.

In the frame of the of the South Tyrol Province CARG project, devoted to 1:10000 mapping of the Vipiteno sheet, the goal of this work is to provide structural and petrological constraints to identify tectonometamorphic units with coherent structural and metamorphic evolution. Preliminary results display significant differences among the reconstructed P-T paths of the Glockner schists and metasedimentary rocks of the post-Variscan cover of the Tux and Zillertal gneisses.

The generally accepted model for the tectonic evolution of the western Tauern Window does not provide full account for these features. Further analyses are therefore needed to unravel earlier stages of metamorphic history of the several units and define the ambient conditions at which nappe stacking occurred.

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Geologic map of the Meridiani region of Mars

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Keywords: Geology, Mars.

The Mars Exploration Rover Opportunity has observed 10s of meters of a more than 600-m-thick sequence of light toned outcrops that characterize the Meridiani region of Mars. Results from the rover analyses have shown that the bedrock contains mineral and textural characteristics that require the interaction of, and possibly an overall formation by, water-related mechanisms in order to be explained. Additionally, remote sensing studies of the region have suggested that the rocks sampled in places by the MER rover consist of many distinct layers extending over an area of more than 3 × 105 km2 spanning 20º of longitude. To address the origin and history of these unique materials, we have completed a geologic, stratigraphic, and thermo-physical properties study of this widespread terrain. Specifically, we have drafted a geological map (at 1:2M-scale) covering the full extent of these water-related deposits that has gone through final peer-review and is now being prepared for USGS publication. This task served several purposes including gaining an understanding of the complex nature of these materials, their potential sources region(s), and their timing of emplacement; as well as to contextualize the observations by the MER rover. Formal geological mapping used a 100-m-resolution THEMIS base map combined with MOLA gridded data. Additional data for mapping included MOC WA images, THEMIS daytime and nighttime IR data, some THEMIS visible data, HRSC mosaics and topography, TES and THEMIS thermal inertia, MOC NA, CTX and HiRISE images. Additionally, we have identified and characterized all craters in the region down to 1.0 km diameter for age-dating. From our mapping, cross-cutting and superposition relations, and crater counts, the geologic history of the region can be reconstructed. The end of the bombardment period is still preserved in the ancient highland cratered materials (Nhc1 and Nhc2) found underlying all other materials. The Nhc2 under-went significant modification, primarily by fluvial erosion and local deposition. Etched terrains (NMe1, NMe2, HNMe3, HNMeu,) likely formed from the Middle-Late Noachian to the Early Hesperian. Several hypotheses have been put forth to explain the deposition of these sub-horizontal highly erodible materials including eolian, lacustrine, groundwater, ice-related, and/or volcanic depositional processes. Crater statistics and stratigraphic relationships suggest that the hematite-rich HMh unit likely formed during the Early Hesperian. The unit is exclusively associated with the etched terrains and its outcrops represent smooth surfaces overlying the HNMe3 unit. Almost contemporarily to the HMh unit, the Hp unit likely started to form around the Early Hesperian in the lowlying plains surrounding the central region of the map. Finally, the Hpct unit is cropping out only in the southwestern portion of the map area as an eastern extension of the large chaotic complex of Iani Chaos located just west of the mapped region.

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Digital modelling and visualization of three-dimensional sedimentary geometries: the Gorgo a Cerbara palaeoescarpment (Monte Nerone, Umbria-Marche Apennine)

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Keywords: 3D modelling, Photogrammetry, Umbria-Marche Apennine, Jurassic, PCP/Basin system, Paleoescarpment.

In recent years, methodologies for three-dimensional digitization of geological objects have considerably grown, giving to geologists several cutting-edge approaches for collecting and manipulating field evidences, and obtaining models starting from a huge amount of raw data. Parallel to the management of field data, digital modelling proves to be a valuable tool, making the raw geological data communicable in interactive mode, and the information retrievable, and allowing to preserve sometimes unique clues of regional or global importance. This methodological enhancement could be dramatically significant in highly complex settings such as the Apennines. In the case study here presented, high-resolution Digital Photogrammetry method was applied to a well-studied, key-outcrop from the Umbria-Marche Apennine. The method allows building a full three-dimensional metric model of any object in space, starting from a suitable number of photographic images (2D object projection) of a static scene taken from different points of view. The technique produces high quality dense point clouds used to generate 3D models comparable to those obtained from LiDAR technology. The concerned site is the Gorgo a Cerbara section (Piobbico, PU), where the NW-facing Jurassic escarpment of the Monte Nerone Pelagic Carbonate Platform (PCP) is magnificently exposed. Here, the Jurassic-Lower Cretaceous basin-fill succession rests on the morpho-structural high margins. The analysed outcrop represents the lowermost tract of the exposed paleoescarpment, and consists of an irregular, silicified, palaeo-surface of pre-rift 'Calcare Massiccio'. On it rests small patches of 'Calcare Massiccio B' facies (drowning succession of footwall-blocks), earliest Pliensbachian in age, and of upper Sinemurian cephalopod-rich pelagites, in the form of epiescarpment deposits. The whole complex is then unconformably covered by basin-fill pelagites of the Corniola Fm., late Pliensbachian in age.

The photogrammetric models return in detail the astonishing stratigraphical, sedimentological and taphonomical framework observed in the field. The complex sedimentary evolution of a PCP margin and the processes triggered within PCP/basin systems are accurately reproduced. Moreover, as 'natural' operation when dealing with digital stuff, all the evidence can be displayed from different perspectives with the same high confidence, further helping in the reconstruction of three-dimensional geometries which is based, as praxis, on field observations and evidence collection. High-resolution photogrammetric techniques further proven to be one the best future candidates, the most low-cost/high-performance, for modelling and visualizing the phenomenological world in the field of geology and palaeontology (but in all the geosciences *sensu lato*) and to construct wide-ranging three- and four-dimensional models rooted on fieldwork, to be used for visualizing geological inferences and reconstructions.

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Current status of 1:3M geologic mapping of Mercury

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Keywords: Mercury (planet), lobate scarps, buffered crater counting, kinematic analysis, planetary geology.

Planetary geological mapping is key to understanding planetary surface processes, dynamics and age correlations among recognisable terrains. After the end of Mariner 10 mission a 1:5M geologic map of seven of the fifteen quadrangles of Mercury (Spudis & Guest, 1988) was produced. The NASA MESSENGER mission filled the gap by imaging 100% of the planet with a global average resolution of 200 m/pixel and this led to the production of a global 1:15M geologic map of the planet (Prockter et al., 2016). However, despite the quality gap between Mariner 10 and MESSENGER images, no global geological mapping project with a scale larger than 1:5M has been proposed so far. Here we present the status of an ongoing project for the geologic mapping of Mercury at an average output scale of 1:3M based on the available MESSENGER data. The area between longitudes 0°E and 360°E and latitudes -22.5°N and 70°N encompasses the Victoria (H02), Shakespeare (H03), Raditladi (H04), Hokusai (H05), Kuiper (H06) and Beethoven (H07) quadrangles that were mapped or are still being mapped at an average mapping scale of ~1:400k with the aim of a final output at 1:3M (e.g. Galluzzi et al., 2016; Mancinelli et al., 2016; Wright et al. 2016) and are thus compatible for merging. All the merged quadrangles show craters larger than 20 km classified into three morpho-stratigraphic classes based on local observations. This preliminary classification is based on both crater degradation morphology and crater superposition relationships in order to assess the relative age of impact events. At this stage, ~22% of Mercury is now covered by 1:3M geologic mapping. Our completion of H05, H06 and H07 will extend the coverage to ~41%. This project will lead to a fuller grasp of the planet's stratigraphy and surface history. Completing such a product for Mercury is an important goal in preparation for the forthcoming ESA/JAXA BepiColombo mission to aid selection of scientific targets and to provide context for interpretation of new data.

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Geology of the Kumeta-Pizzuta ridges (NW Sicily)

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Keywords: Geological map, Sicily, Backthrust, Transpressive fault.

We present a 1:25.000 scale geological map of the Kumeta-Pizzuta ridge in north western Sicily (Italy), which was achieved by integrating stratigraphic, structural and geophysical data.

In this area the tectonic edifice results from the piling-up of deep water-, carbonate platform- and pelagic platform-derived tectonic units (Imerese and Sicilide, Panormide and Trapanese domains respectively) originated by deformations of former southern Tethyan continental margin.

The structural setting shows interference of subsequent tectonic events, different type of structural styles, and different-scale deformational patterns. Early overthrust of the Imerese on the Trapanese units (since late Serravallian) was followed by wedging at depth of the Trapanese units (after Tortonian). The wedging implied re-embrication and shortening into the overlying Imerese Units and produced main folding and compressive to transpressive structures along the Kumeta-Pizzuta Ridge.

Seismic reflection profiles image the main E-W trending anticlines have been offset by high angle reverse to transpressive faults that merge at depth with low angle, regionally widespread, flat decollement surfaces that show, in this sector, a northward tectonic transport. This setting supports backthrusting along transpressional faults in the study area, ruling-out that the Kumeta ridge is a positive flower structure related to a near-vertical deep, crustal, shear zone as formerly suggested.

CARG Project: land-sea geological cartography of the Campania Region coastal sectors

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Keywords: Campania Region, Land-Sea geological cartography, 1:10.000 and 1:50.000 scale.

In December 1999 the Regione Campania promoted its participation in the National CARG Project and co-financed the regional geological maps of emerged and coastal marine areas. The maps include the 0 -200 m depth and the related emerged coastal sector. These maps have been surveyed at 1:10.000 scale while a synthetic 1:50.000 versions was also derived for the National Project CARG. In this way, the use of same scale for the survey of emerged and submerged areas allow a land-sea correlation.

Moreover the areas around the coastal in the Gulf of Naples have been mapped by direct methodology, by subacqueous geologist (bathimetric range from 0 to -30 m). This significant aspect for the study of submerged marine areas represent the establishment of homogeneous criteria for the geological survey between coastal emerged and submerged zones.

The above mentioned criteria result in a tool to map in great detail, the underwater geology strategically useful for territorial planning procedures and risk evaluation in a densely anthropized environment with socio-economical value, characterized by high geomorphological dynamism and specific vulnerability.

This modern land-sea geological 1:10.000 cartography of coastal sheets respond to new regional needs in order to face, consciously and responsibly, the complex problems of coastal sectors. This type of cartography has already been used for "Piano Stralcio dell'Erosione Costiera" dell'Autorità di Bacino del Sarno (today, Autorità di Bacino della Campania Centrale) and now form the basic data set for the integrated coastal planning of Campania region. At present, only part of the land-sea geological cartography of Campania Region has been printed and is avaliable (series of cartography of Campania region coastal maps in 1:10.000 scale) with the associated illustrative notes.

Carta Geologica Regionale 2011. Isola di Ischia, scala 1:10.000. Progetto CARG, Regione Campania. Con Note Illustrative.
Carta Geologica Regionale 2012. Isola di Procida, scala 1:10.000. Progetto CARG, Regione Campania. Con Note Illustrative.
Carta Geologica Regionale 2012. Isola di Capri, scala 1:10.000. Progetto CARG, Regione Campania. Con Note Illustrative.
Monti L., Donadio C., Putignano M.L., Toccaceli R.M. 2003. Linee guida al Rilevamento geologico subacqueo (scala 1:10.000). Progetto CARG Regione Campania, ed. Regione Campania, 93 pp.

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Geologic map of the Shakespeare Quadrangle (H03) of Mercury

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Keywords: Mercury, Shakespeare, geological mapping.

The NASA Mariner 10 probe covered about 45% of Mercury's surface allowing the production of 1:5M-scale geologic maps of seven out of fifteen quadrangles in which planet's surface is divided. Despite the later NASA MESSENGER mission has covered 100% of the planet's surface with a better global average resolution (200 m/pixel), only a global 1:15M-scale geologic map of Mercury has been produced (Prockter et al., 2016). Using the MESSENGER images and the available *Mercury Laser Altimeter* DTMs, a 1:3M-scale geological map of the H03 Shakespeare Quadrangle has been compiled. The quadrangle covers an area of ~5M km^2 at middle latitude of the northern hemisphere of Mercury. The mapping was performed in a GIS environment and operated on a georeferenced monochromatic basemap at 166 m/pixel resolution. The planet surface is characterized by impact craters, tectonic landforms and several plains deposits classified as smooth, intermediate, and intercrater plains materials (Schaber & McCauley, 1980). Craters with D > 20 km and their related materials are distinguished into three morpho-stratigraphic classes (c1-c3, see Galluzzi et al., 2016) according to their overlapping relationships. The most represented structural features in H03 are the lobate scarps, interpreted as thrusts, and wrinkle ridges. Tectonic structures mainly occur in the western sector of the map nearby the Caloris basin, the largest impact crater on Mercury and the most prominent geo-morphological feature within H03. Its widespread ejecta are distinguished into units pertaining to the *Caloris Group* (McCauley et al., 1981) and form a discontinuous annulus around the basin.

The presented geologic map represents a more detailed cartographic product with respect to the previously released 1:5M map of the quadrangle (Guest & Greeley, 1983). In fact, the geologic boundaries were redefined and previously unmapped tectonic landforms were detected. The new map will support future local studies and will help the targets selection for the scheduled ESA-JAXA BepiColombo mission to Mercury.

This research was supported by the Italian Space Agency (ASI) within the SIMBIOSYS project (ASI-INAF agreement no. I/022/10/0).

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Interoperable sharing and visualization of geological data and instruments: preliminary results

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Keywords: Geology, Spatial Data Infrastructure, Semantic Harmonization, SensorML, O&M, GeosciML.

On a global scale, different governmental agencies implemented dedicated Spatial Data Infrastructures (SDI) to publish geological, geotechnical and geothematic maps, datasets and metadata. In most cases, the geoportals of SDI use different types of both visual and textual representation of the information and the geological data of each nation are structured in a different way. Moreover, geoportals usually miss information on geological instruments and, often, the data collected directly from these instruments.

To enable an interoperable sharing of geological and geothematic maps and data, international and national geoportals mainly adopt the Open Geospatial Consortium (OGC) standards and recommended services, such as Web Map Service, Styled Layer Descriptor, Web Feature Service, Web Coverage Service and Catalog Service for the Web; this methodology however, is still lacking in the harmonization of data and their visualization. This gap, for geological and geomorphological maps and data, was removed by developing two models: GeoSciML (Sen et al., 2005) and GeoSciML-Portrayal (Richard et al., 2012) that also allow a semantic enrichment through the use of thesauri.

Anyway, description and sharing of measuring instruments still missing while this capability is given by Sensor Metadata Language standard (SensorML) (Boots et al., 2007). In relation to data sharing from instruments a chance is given by Observations and Measurements standard (O&M) (Cox, 2003). Links between O&M and GeoSciML are widely recognized in relation to delivery of geological sampling and analytical data (Richard et al., 2012).

Standardized common interfaces, schema, and syntax for information en-coding is a fundamental requirement for SDI. As discussed, GeoSciML and GeoSciML-Portrayal meet these requirements for Geological and Geomorphological Maps and O&M allows to add geological sampling and analytical data. Exploiting controlled vocabulary resources is a step forward in the full realization of interoperability at the semantic level. Anyway, description and sharing geological and geotechnical instruments information is still missing, though this additional information can enable quality control procedures and improve data comparison.

To tackle this gap we tested, a preliminary SensorML modeling, in eXtensible Markup Language, for geological (coring tools) and geotechnical (dynamic penetrometers) instruments defining, for each instrument: identification-code, sensor type, manufacturer and output parameters. Sensor type and outputs parameters definition have been borrowed from the terms present in the "Italian Thesaurus of Earth Sciences", (ThIST), in order to harmonize and semantically enrich metadata. The test proved that SensorML has the capabilities to share semantically enabled information about these instruments in a distributed SDI and view them in a geoportal.

It is worth noticing the need for the development of graphical user interfaces for editing SensorML for geological and geotechnical instruments; a solution is offered by the EDI metadata editor (http://edidemo.get-it.it); future works will prepare EDI templates for geological and geotechnical domains.

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GIS-aided detailed geological mapping for local seismic hazard studies: the Avezzano town (Fucino basin, Italy)

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Keywords: GIS-technique, geological mapping, seismic microzonation, HVSR, subsurface geological model.

The seismic microzonation of the Avezzano town (Fucino basin, Italy) allows to perform a multidisciplinary approach to the seismic site characterization in a deep continental basin setting. Geological, geomorphologic, hydrogeological, structural, geognostic and geophysical data are matched together to define the subsurface geological model and the landslide susceptibility. The synthesis, represented by thematic maps and geological cross-sections, has been made by the combination of raster data layers stacked on top of each otherin GIS environment. The seismic microzonation highlighted several critical issues related to the presence of active and capable faults, stratigraphic amplifications, liquefaction and slope instabilities. In this work, GIS-techniqueare used for evaluating the rock-slope instability and for processing different data, useful for the reconstruction of the buried bedrock.

In order to assess the susceptibility of rock-slope instability along the carbonate relief bordering westward the urbanized area, a kinematic slope stability analysis following the Markland test has been performed combining geomechanic and DTM data. Several data layers (slope, aspect and joint attitude), related to features that are thought to be connected with slope instabilities, are processed in GIS environment. The investigated area is locally characterized by high rock-slope instability, mainly related to topple failure mode.

One of the main goals of seismic microzonation is the reconstruction of the subsoil geological model in order to define the structural complexities, the geometry of the buried bedrock interface and sedimentary bodies. This is achieved integrating field data, well data and geophysical investigations. The fundamental resonance frequency (f_0) obtained from noise Horizontal to Vertical Spectral Ratio (HVSR) technique allows to estimate the depth of the main impedance contrast, which is related to the top of the geological bedrock. We performed numerous HVSR analyses along transects orthogonal to the border of thebasin and we obtained a fundamental resonance map. The f_0 contouring shows a negative trend eastward, in agreement with the deepening of the continental deposits constrained by deep wells, and an alignment of the isolines parallel to the border of the basin. Moreover, the HVSR results, calibrated with the available geognostic data, allow us to constraint the geometry of the bedrock and, to some extent, the location of sharp steps due to bedrock faults. This has obvious implications for estimating the local seismic response. This technique, which is easy, quick and cheap to apply over large areas, might also find several less obvious applications in any geologic study which require the reconstruction of buried geometries of a stiff bedrock (thickness of sedimentary covers, location of buried faults, fault displacements, etc.).

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Multilingual planetary maps for children: a visual-scientific experiment

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Keywords: planetary mapping, planetary geology, cartography.

In this project a new series of planetary maps for young readers (8-12 years old) as part of the outreach activity of the ICA Commission on Planetary Cartography and also supported by the Europlanet 2012 Outreach Funding. The maps are based on real photomosaics or computer generated data and then redrawn as artwork.

We selected six planetary bodies (Venus, the Moon, Mars, Io, Europa and Titan) which may result more attractive for children and invited six graphic artists with experience as illustrators of childrens'books, to create the maps in the visual language of children: András Baranyai for Venus, László Herbszt for the Moon, Csilla Kőszeghy for Mars, Panka Pásztohy for Titan, Dóri Sirály for Io, and Csilla Gévai for Europa).

Although the overall structure of the maps look similar, the visual approach to draw each map is absolutely different. We consider this series as a visual-scientific experiment: an artistic view in a scientifically correct way, basically our intent was to create cartographically and scientifically correct maps but, at the same time, attractive and understandable for children. Visual design is becoming of increasing importance in communicating science from news media to university levels.

The illustrators and the technical-scientific editor worked together on the maps from the beginning to the end of the project. The illustrators had the freedom of choosing a visual approach but had the limitation to strictly follow the projection and, with sufficient generalization (e.g., simplification, enhancement), to depict the surface landforms where they occur.

The final marginal text from the explanations to the legend was translated into 11 languages spoken in Europe (Hungarian, German, Spanish, Portuguese, Polish, French, Romanian, Russian, Italian, Romani, and English). The translation was made by scientists which are expert in the planetary and terrestrial disciplines, to ensure a scientific accuracy. The most unique language version is Romani (Gipsy), which is spoken in several Central European countries, and for which version several new words had to be created.

The next step will be to show the encounter hemispheres of Pluto and Charon with cooperation with the NASA New Horizons Team.

The maps and multilingual translations are available on line here:
https://childrensmaps.wordpress.com/international-versions/

We would also like to draw the attention to a planetary map competition sponsored by ICA, information available here : https://planetcarto.wordpress.com/2016/04/22/mars-exploration-zone-map-competition/

Hargitai H., Gede M., Zimbelman J., Kőszeghy C., Sirály D., Marinangeli L., Barata T., López I., Szakács A., Dębniak K., Feuillet T., 2015. Multilingual Narrative Planetary Maps for Children. In: Robbi Sluter C., Madureira Cruz C.B., Leal de Menezes P.M. Eds., Cartography - Maps Connecting the World, Lecture Notes in Geoinformation and Cartography, 17-30, Springer International Publishing.

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Correlation of meta-sedimentary and sedimentary successions for the implementation of the "GeoPiemonte Map" at the 1:250.000 scale

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Keywords: Carta Geologica del Piemonte, discontinuities, synthem.

In this contribution, we illustrates a few examples of application of the methodology used to define the Carta Geologica del Piemonte (GeoPiemonte Map) at the 1:250.000 scale (Lombardo et al. 2016).

Lithostratigraphic criteria have been mainly adopted in the definition of this map, and the rocks have been subdivided and/or grouped into different Geological Units consisting of formal and/or informal formations or members.

On the basis of their chronostratigraphic evolution and the suggestions of the abundant literature, the recognized units have been ascribed in the legend to their original tectonic context, e.g. the palaeoEuropean or palaeoAdriatic continental margins, the ocean-continent transition zone, the Liguria-Piemonte and Vallesan oceanic domains, and the syn-orogenic Cenozoic basins.

The non-metamorphic sedimentary successions were subdivided into UBSU (Chang, 1975) or Synthems, bounded by unconformities due to major tectono-sedimentary events.

In the Tertiary Piedmont Basin succession, for example, the D2 discontinuity surface is related to the Burdigalian event that leads to a major reshaping of the basin areas in structural highs and lows. The overlying Synthem BTP2 consists of mainly carbonate shallow water deposits laterally passing to epibathyal carbonate successions and with occurrence of resedimented deposits in correspondence of the structural highs. The correlation of discontinuity surfaces through several tectonic units of the Maritime and Ligurian Alps allowed to map three synthems in the non-metamorphic Triassic-Cretaceous sedimentary successions of Dauphinois, Provençal and Briançonnais units.

Analogous methodology has been applied also to the metamorphic sedimentary successions resting on the different pre-Triassic tectono-metamorphic units of the western Alps. However, for these rocks the proposed subdivisions must be more correctly indented as "para-synthems" and were correlated through the different units of the Western Alps on the basis of their primary lithologic and stratigraphic characters and related chronostratigraphic evolution. This approach has been applied to subdivide and/or group the post-Variscan rocks occurring in the Briançonnais units and in the meta-sedimentary cover of the crystalline massifs. As an example, the lower part of the Dora Maira and Ambin Mesozoic covers, although they unconformably rest on different continental crust units and show quite different distribution and thickness, are ascribed to the same para-synthem; this consists of prevailing Permian-Lower Triassic quartzites and conglomeratic quartzites and record the progressive transition from continental to marginal marine environments at the onset of the Alpine sedimentary cycle.

Lombardo V., Piana F., Fioraso G., Irace A., Mimmo D., Mosca P., Tallone S., Barale L., Morelli M. & Giardino M. 2016. The Classification Scheme of the Piemonte Geological Map and the OntoGeonous initiative. Rend. Online Soc. Geol. It., 20, 117-120

Chang K.H. 1975. Unconformity bounded stratigraphic units. Geol. Soc. Amer. Bull., 86, 1544-1552.

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Concepts and methods for the classification of the geological units of the "GeoPiemonte Map" at the 1:250.000 scale

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Keywords: GeoPiemonte Map, geological units, classification.

The geological map of Piemonte (GeoPiemonte Map), realized by CNR IGG Torino and ARPA Piemonte is an "in-progress" representation of the geology of the region, available as a WebMapService. The GeoPiemonte Map is supported by a large database, which is being completed, semantically based on controlled vocabularies and a dedicated ontology (Lombardo et al., 2016). The first release of the GeoPiemonte Map, accomplished as a graphical issue at the 1:250.000 scale, was realized with the approaches and methodologies illustrated in the followings. The GeoPiemonte Map adopted the IUGS GeoSciML vocabulary (http://www.geosciml.org), compliant with the INSPIRE EU Directive (Data Specification on Geology v.2). The GeoPiemonte Map was built firstly using lithostratigraphic criteria, i.e. subdividing rocks into Geological Units (GU, formal and/or informal formations or members) on the basis of their compositional and textural features. The GeoSciML "Geologic Unit" Taxonomy was chosen as reference conceptual scheme to establish the hierarchy of the regional-to-local scale geological subdivisions, while the GeoSciML "Earth Material" and "Rock Material" Taxonomy was used for the lithological description of the Mapped Features. The discontinuities (of both primary and secondary origin) were classified following the GeoSciML "Geological Contact" and "Geologic Structure" Taxonomy. The reconstruction of the geological evolution, upon which the subdivisions of the Map Legend were grounded, was displayed by the definition of a number of main "Geologic Event" (remarkable modification of a given geological context induced by tectonic, sedimentary or petrogenetic processes). Many of these Geologic Events are represented by regional-scale discontinuities preserved in the geological stratigraphic record and correlatable across different geological domains. The GU of the GeoPiemonte Map were thought as parts of a single first-order domain: the Alps-Apennines orogenic system. The GU were then ascribed to their original paleotectonic context, namely the palaeoEuropean or palaeoAdriatic continental margins, the ocean-continent transition zone, the Liguria-Piemonte and Vallesan oceanic domains, the syn-orogenic magmatic bodies and sedimentary basins, as well as some main large scale "tectonic slice zones". The non-metamorphic sedimentary successions of the main syn-orogenic basins (Tertiary Piemonte Basin and Alpine Foreland Basin) were subdivided into UBSU (Chang, 1975) or Synthems, each ones resulting from major tectono-sedimentary events. Similarly, the meta-sedimentary succession resting on the main tectono-metamorphic units of Western and Ligurian Alps were correlated across these units and subdivided into informally defined "para-synthems", separated using the same chronostratigraphic subdivisions used for the non-metamorphic synthems.

Chang, K. H., 1975. Geol. Soc. Amer. Bull., 86, 1544-1552.

Lombardo V., Piana F., Fioraso G., Irace A., Mimmo D., Mosca P., Tallone S., Barale L., Morelli M. & Giardino M. 2016. The Classification Scheme of the Piemonte Geological Map and the OntoGeonous initiative. Rend. Online Soc. Geol. It., 39 117-120.

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Remote sensing technologies and GIS 3D applications for geological and geomorphological cartography realization and improvement

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Keywords: Remote sensing, GIS 3D, Geological and Geomorphological Map.

The new aircraft and sensor technologies afford territory analysis methodologies that until now were difficult to practice, in geological field these techniques are still developing. At the same time, the systems dedicated to the management and processing of image and data obtained from these technologies have gradually improved, allowing user to store and make more and more available an important amount of informations. In the present study we propose an innovative working method capable of reducing to a minimum the entities of both costs and field work, going to represent a substantial support, sometimes an alternative, to the in situ geological survey. It is the application of digital photogrammetry based on Structure from Motion algorithms (SFM), expeditious, economic and effective technic for three-dimensional surveying and mapping of large areas of particular geological and geomorphological interest. With constant technique improvements for data acquisition and processing, the photogrammetric processing products, such as three-dimensional point clouds, Digital Elevation Models (DEM) and orthophotos with a detail and accuracy always better, represent a new frontier in territory analysis and monitoring.

The acquired data are elaborated within the new ESRI ArcGIS Pro environment that affords to analyze in practical way the three-dimensional models and to directly digitize in 3D environment, creating consequently an innovative geothematic database. Using this platform the digital models coupled and integrated with the geological surveys data can be used in order to improve three-dimensional geologic photo interpretation. In this way it is possible to characterize the main ductile and brittle geologic elements (e.g. lithological contacts, faults, folds, etc.) with absolute precision benefitting of a three-dimensional visualization of the area from more points of view and be inserted into a database by acquiring directly the complete spatial information. The data can be georeferenced and inserted in the geological and/or geomorfological map. The software makes it possible combining 2D data (*map*) and 3D (*scene*) and allowing user to work by loading multiple views of the same data or the same view for different data. In this way geologic maps, aerial and/or satellite images to high resolution, topographic maps, infrared images, can be loaded in the 2D window while DEM to various resolution can be loaded in the 3D window on which it is possible "to drape" the various types of images loaded in the 2D window. From direct comparison between bidimensional and three-dimensional images it is possible to directly edit points, lines or polygons improving in some cases the precision and the reliability of the photointerpreted geologic data.

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Development of a thermal conductivity map to identify areas potentially prepared for installation of geothermal heat pump systems. The case study of Sardinia (Italy)

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Keywords: Thermal conductivity map, Low enthalpy geothermal energy, Heat pump.

In planning geoexchange systems for a corrected dimensioning of the field probes, a careful evaluation of the thermal properties is needed. Among them the evaluation of thermal conductivity of hosting rocks can be made only through a careful geological characterization of the chosen site. The goal of the research is to find the key parameters that could allow to product a map of thermal conductivity. Nowadays, available data measured on lithologies of the Italian territory are few and hard to find.

Data of thermal conductivity from literature have been compared with data carried out from in situ detailed investigation. Then, a thermal characterization of the lithostratigraphic units of the legend of the Geological map of the Sardinia Region realized for territorial planning (at 1:25,000 scale) was made. A value of thermal conductivity has been assigned to 778 lithostratigraphic units, and, wherever possible, for each of which it has been determined according to the individual lithologies that make up the unit. The main problem encountered in attributing the value is related to the type of information contained in the description of the lithological units. Those having a general description, in order to respond to different needs, often give information that hardly lend themselves for the purposes of this study. In fact, the classification that frequently characterizes the geological maps is based on lithostratigraphic criteria, that is the pooling and division into units with different hierarchical order, on the base of the lithological and stratigraphic characteristics of the rocks bodies. It happens that the same unit may be include rocks or lands with a different thermal behaviour. The individual lithologic components of each unit has been detected, valuing the proportions with which these are present, identifying an equivalent thermal lithotype. This approach not always allowed us to identify an equivalent thermal lithotype, so it was not always possible to assign a value of thermal conductivity.

This reclassification of the different lithostratigraphic units allowed to make three maps of thermal conductivity in condition of saturated, unsaturated and without water content.

From the performed maps arise that the more conductive areas are represented by out crops of the crystalline Palaeozoic Basement. In particular the low-grade metamorphic complex of the Outer and Nappe Zones, the Migmatitic Complex and the Late-Variscan Granitic Batholith. On the contrary, the areas that have values of thermal conductivity from low to very low are represented by the Cainozoic sedimentary covers in the Campidano Graben and the different intramountain basins filled from alluvial and/or lacustrine sediments.

The thermal conductivity maps in this way realized are fundamental to provide a preliminary assessment of the thermal potential of the site and at the same time identify the most suitable areas to plan such systems.

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Extraterrestrial geological maps: examples from sedimentary units on Mars

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Keywords: Mars, Geological Mapping, Fluvio-lacustrine deposits, Spring deposits.

Extraterrestrial geological mapping is undergoing a dramatic evolution due to the continuously increasing amount of available data both qualitatively and quantitatively. This is true especially on Mars, where the combination of high resolution imagery, topography and hyperspectral data, allows an unprecedented Earth-like approach, locally enhanced by the presence of although limited ground truth in correspondence of rover landing sites. As a consequence, primary process of the units' formation and secondary processes of erosion can be distinguished, thus leading to the production of 'true' geological maps (with all the obvious limitations associated to remote observations) instead of 'simple' geomorphological mapping. This scientific as well as philosophical transition is well exemplified by the differences between Scott and Tanaka (1986) and Tanaka et al. (2014).

We present two examples of geological maps from mostly sedimentary settings, representing putative fluvio-lacustrine (Eberswalde crater; i.e.: Pondrelli et al., 2008) and mixed evaporite-spring deposits/aeolian units (Firsoff crater and surrounding plateau, Pondrelli et al., 2015). Units have been characterized using their most 'objective' characters, including presence/absence of layering, color, texture, sedimentary structures, hints on composition where possible as well as their position within the stratigraphic sequence. Boundaries between the units have been distinguished between continuous, disconformable and nonconformable. Where image resolution does not allow such a distinction, a more general definition has been used. A level of more interpretative information, including tectonic, primary/depositional (i.e., fan delta, spring mounds, etc.), secondary/erosional (i.e., yardangs, craters, etc.) has been included, with also the indication of the preservation of the different features.

We plan to use this approach as a basis to reconstruct the vertical and lateral stratigraphic relations between the different units and their depositional architecture with respect to the post-depositional erosion in order to perform a source-to-sink analysis of the sedimentary systems. Thus, the interpretation would not be based on a single morphological evidence, but on a suite of related morphologies.

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Geological map of the Centuripe-Mt. Judica region: a picture of the external orogenic domains in eastern Sicily

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Keywords: Eastern Sicily, thrusting, strike-slip tectonics.

A detailed geologic field mapping, combined with structural and remote sensing analyses (interpretation of aerial photograps, satellite image and Digital Elevation Model) has been carried out in a significant segment of external orogenic domains, in eastern Sicily. The study of this region, extending for about 380 km^2 along the frontal thrusts of the Maghrebian Chain, provides several fundamental constraints in order to define the geometry of the Messinian to Quaternary tectono-sedimentary features and to reconstruct the post-Tortonian tectonic evolution of the orogenic belt. In this area two main geological and structural domains, separated by a prominent NW-SE dextral shear zone, can be distinguished: the northeastern sector, which includes the Centuripe Basin and the southwestern sector of Mt. Judica area. The former is characterized by huge volumes (km-thick) of an allochthonous body mainly constituted by Numidian Flysch that forms two distinct superimposed nappes, emplaced towards the SE, overthrusting on a Langhian-Tortonian pelagic sequence. This allochtonous body is unconformably covered by Messinian to Pliocene deposits that infill a perched basin, the Centuripe Basin. The depocentral succession of this basin consists of Messinian evaporite deposits (laminated gypsum) covered by the early Pliocene pelagic marls (Trubi Fm.). At the top Middle-Upper Pliocene terrigenous deposits form two distinct cycles. The lower one mainly consists of marly facies, containing N-ward prograding turbidites intercalations to the south of the basin. The upper one consists of sandy facies, onlapping onto the lower one. The entire sequence of the Centuripe Basin is intruded, at different stratigraphic levels, by brecciated clays fed by mud diapirs. This region represents a useful area for analysis of the structural pattern associated with shale tectonic processes. The southwestern sector is composed of the S-verging tectonic slices of basinal Meso-Cenozoic succession, capped by Upper Oligocene-Middle Miocene turbidites, which developed by the tectonic inversion of the Africa continental margin (Mt. Judica Unit). These tectonic slices also involve a thin allochthonous horizon, mainly made of the Upper Oligocene-Early Miocene Numidian Flysch, which now form small E-W elongated klippen, preserved at the core of the main footwall syncline. At the leading edge of the imbricated stack of Mt. Judica, a tectonic wedge composed of Tortonian to Early Pleistocene deposits formed at the flexured margin of the Hyblean Foreland succession. At depth, the whole frontal units are emplaced on Early Pliocene horizons at the top of the Hyblean succession. We propose a tectonic evolution of the area starting from the Tortonian when the surface thrust deformation was almost completed in both the two adjacent sectors. During the Messinian-Quaternary, the Mt. Judica imbricates overthrust the Plio-Pleistocene foredeep deposits on the margin of the Hyblean Plateau, while in the adjacent accretionary wedge the prominent mud diapirism and the associated local shale tectonics suggest still active motions along a deep sole-thrust. The main dextral shear zone, corresponding at depth to an abrupt change of the thickness and magnetic susceptivity of the crust, could be interpreted as the boundary separating the accretionary wedge still migrating towards the subducting Ionian Basin, to the north, and the deformed African margin units, to the south.

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The geological mapping as a tool for the seismic microzonation: the case of the urban area of Catania (eastern Sicily)

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Keywords: Paleo-valleys, marine terraces, geological map.

A new geological map of a large sector of the urban area of Catania have been created integrating the conventional 2D surface geological field mapping (1;10.000 scale) with subsurface information obtained from the interpretation and the interpolation of 177 available logs and several geophysical data, analyzed during the first level of seismic microzonation studies. The whole dataset has been filed in the seismic microzonation geodatabase, managed by using ArcGIS 10.2 platform for the map restitutions. The geological setting of the town is the result of the combination between the active tectonic uplifting, producing the deep entrenchment of river valleys, and the volcanism, causing the rapid infilling of the topographic depressions. The subsurface architecture is thus very variable, mostly depending on the paleotopography, modelled on the sedimentary substratum and concealed by the volcanic cover. We reconstructed the sub-volcanic topography combining geological surface data with the available well logs. The interpretation of the ages of the buried morphological features was based on the correlation with Late Quaternary eustatic sea-level changes, corrected for the tectonic uplift affecting the area. The main elements (e.g. valley axes, marine terraces, scarps) of the buried morphology have been represented in the map by using linear and areal features. This approach provides further information to constrain the age of the volcanic cover in the different sites of the town. According to our study, two distinct stages of river entrenchment can be recognized. The main buried valleys have been entrenched within the marine terraces of the OIS 5 (125 ka – 80 ka), reaching, near the coast, a depth of about 36 m b.s.l.. The valleys are flanked by the Early-Middle Pleistocene marly clays, with interleaved volcanoclastic deposits, and are filled by an alternation of lava flows and fine grained alluvial deposits, which is capped by the marine sands of the OIS 3.3 (60 ka). Beneath the historical downtown, the old valley infilling is modelled by a younger channel that is entrenched within the marine terrace of the OIS 3.1 (40 ka). This valley reaches the depth of about 15 m b.s.l. and is infilled with Holocene lava flows and alluvial deposits. The lava cover in the eastern portion of the town overlies the Holocene marine deposits, ranging in depth from 2 m to about 15 m b.s.l. The new version of the geological map of Catania and the related even if projected for the seismic microzonation, could represent a document for other application regarding the engineering geology and hydrogeology.

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Shaded bedrock topography map of Leonessa Plain

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Keywords: 3-D bedrock configuration, 3-D modeling, Leonessa, Central Apennines, Structural geology, Gravity.

The shaded bedrock-topography map of Leonessa Plain (hereafter LP) depicts the 3-D bedrock surface configuration and elevation of Leonessa basin. The LP, the test-area of this study, is located in the heart of the Central Apennines, in the northern Latium region. It falls inside of the Rieti province and specifically on the territory of the city of Leonessa.

In order to model and map the bedrock configuration, an integrated review of exiting geological and geophysical data (69 boreholes, 5 well logs, 130 Dynamic Penetration Test, 8 Seismic Refraction Investigation, 53 MASW and 1 Down Hole) were combined and compared with the new data provided by 333 gravity stations and 29 single station ambient vibration recording (Skrame & Di Filippo, 2015). All the data were inserted in a GIS Geo-database in a World Geodetic System WGS 84 / UTM zone 33N projection (Skrame, 2015). The *3dGRVT* software was used to realize the 3D gravity model of the plain that allowed reconstructing the structural geological map of the LP. It shows the distribution of the main negative gravimetric axes and the geometries of the normal faults.

Referring to the obtained paleo-morphology we were able to reproduce and to define the 3-D bedrock configuration of the LP. The 3-D model shows the geometry of two sedimentary sub-basins, one located at the northwestern sector between the Villa Pulcini and the Villa Braddi and the other one at the southeastern sector of the LP, between the Vallunga and Vallimpuni villages. These two areas are interpreted as two different sedimentary basins (Skrame, 2015).

This newly completed Bedrock Geologic Map of LP covers an area of about 63 km^2 and is the first image of the buried morphology of the LP ever made; it also distinguishes the thickness of the alluvial-lacustrine sedimentary infilling that cover much of the plain. The alluvial-lacustrine sediments thickness varies in accordance with the topography and surface geology reaching the maximum thickness of about 250m (Skrame, 2015). As the resulting map indicates the 3-D bedrock surface configuration e consequently the distribution and the thickness of the alluvial-lacustrine sedimentary infilling, it can be essential for many environmental, engineering, geophysical and geotechnical applications.

The authors wish to thank prof. Gabriele Scarascia Mugnozza and the following ENEA colleagues for their support and assistance with the field work: Guido Martini, Antonella Paciello. We also thank the municipality of the Leonessa for providing useful data.

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New bedrock surface topography map of the Rieti Plain

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Keywords: Rieti, Central Apennines, Gravity survey, 3-D bedrock configuration, 2D Gravity modeling.

A research approach that integrated different geophysical methods for local subsoil evaluation was carried out for the seismic microzonation study of the city of Rieti. A detailed gravity survey was made to reproduce the 3-D bedrock configuration of the Rieti Basin (hereafter RB); a typical intra-mountain depression of Central Apennines, related to a still active tectonic extensional regime. The RB is characterized by thick Quaternary fluvial-lacustrine deposits (gravel, sand and clay) overlaying the "Umbria-Sabina" units (a pelagic succession of carbonate-siliceous-marly sediments) (Ciccollella et al., 1995).

The study involved a test area of 35 km^2 occupied by 110 gravity stations. The new gravity measurements were merged with the gravity data of the 358 gravity stations collected during the 1995 gravity survey (Ciccollella et al., 1995). The gravity data resulted from the network adjustment were used to calculate the Bouguer anomaly map. To realize the 2-D gravimetric models of the RB, the *3dGRVT* software (developed by prof. Michele Di Filippo) was used. The software calculates the synthetic gravity anomaly for every gravity station basing on the topography, on the hypothesized bathymetric map and on the density contrast between the bedrock and the overlaying deposits. A realistic density of 2,15 g/cm^3 for the unconsolidated Quaternary deposits, a density of 2.50 g/cm^3 for the Travertine and a density of 2.60 g/cm^3 for the Meso-Cenozoic pelagic basin deposits were used (Skrame, 2011).

An integrated review of exiting geological and geophysical data were combined and compared with the 2-D gravity model in order to better depict the 3-D bedrock configuration and distinguish the thickness of the unconsolidated Quaternary sedimentary infilling that cover much of the plain. All the data were inserted in a GIS Geo-database in a World Geodetic System WGS 84 / UTM zone 33N projection (Skrame, 2011).

The new bedrock surface topography map of RP provides a new more detailed and representative image of the buried morphology, and gives a more accurate evaluation of the thickness of the Quaternary sedimentary infilling. It can be used as a powerful planning tool for future activities in near-surface engineering investigations such as 3rd level of the seismic microzonation studies.

The authors wish to thank Prof. Gabriele Scarascia Mugnozza and the ENEA colleagues for their support and the fruitful collaboration.

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3D geological model of Central Archaeological Area of Rome for seismic hazard assessment

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Keywords: 3D geological model, Rome, seismic hazard assessment, archeaological areas.

Correlation among borehole, outcrop, electrical resistivity tomography and ground penetrating radar data from a campaign of drilling and geophysical survey has allowed to reconstruct with detail the subsoil structure of the Palatine hill and Foro Romano (Rome, Italy), concerning both the natural geological substratum and the overlying anthropogenic cover (Mancini et al. 2014; Moscatelli et al. 2014). In the investigated area, several incised valleys and interfluves made of fluvial sediments and pyroclastites, overlaying the geological bedrock of Rome (i.e., Monte Vaticano Fm.), are detected below the anthropogenic deposits (masonry and infilled ground).

A 3D model of the subsoil of the study area is presented here, obtained through the following three steps. 1) Production of 11 cross sections and a geological map (scale 1:2.000) with GIS software. 2) Selection of six relevant key horizons (i.e., basal unconformities of fluvial origin, bases of pyroclastic flow units, base of anthropogenic unit), that bound groups of stratigraphic units having similar lithotechnical features and parameters for numerical simulation oriented to seismic responses analyses. 3

The resulting 3D model shows geometries and spatial distribution of the geological bodies highlighting buried valleys where 2D amplification effects were calculated (Pagliaroli et al. 2014).

The aim of 3D reconstruction is to provide a base for an advanced 3D numerical modelling of amplifications to be compared with the 2D simulation results.

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Multi-Spectral Mapping of Martian soils and Terrestrial analogues

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Keywords: CRISM imaging, clay minerals, soils.

Compact Reconnaissance Imaging Infrared Spectrometer for Mars (CRISM) instrument on board the Mars Reconnaissance Orbiter mission (MRO) provides near-infrared hyperspectral imager used to define the mineralogical composition of the Martian crust. In analogy with the Earth's, CRISM are equipped with sensors that analyze the signal received from a planetary surface at different wavelengths coupling two related but distinct technologies as the spectroscopy and the remote sensing. We use a multidisciplinary approach coupling CRISM imaging data with morphological pedological and mineralogical investigations to map the region of interests (ROI) composed by clay minerals in the Margaritifer region on Mars. We use this methodology to create the geological and geomorphological maps of the study area. In addition the occurrence of clay minerals on Mars are compared with the terrestrial analogues soils on the Earth and was used as a tool to reconstruct the paleoclimatic, geological and chronological evolution of the Margaritifer Region on Mars. CRISM data show clays widely exposed in Margaritifer region on Mars, where we detected allophane (poorly crystalline clay) as well as vermiculite, chlorite and smectite. We find good analogies between Etna volcano and Cerviero mount choose, as terrestrial soil profiles analogues analyzed using X-ray diffraction and the Martian terrains, as inferred from remote observations, in terms of bedrock composition and clay mineralogy. We associate the different clay minerals formation to chemical weathering alteration and hydrotermal alteration. Furthermore, the geological setting of Margaritifer region on Mars, observed using CTX and HIRISE images, show that these clay deposits are generally located in morphological depressions, where we also observed polygonal structures (size range between 10-35 m) resembling terrestrial mud cracks, as potential evidence of small lacustrine basins. Although weathering processes are reasonably faster under humid and warm climate conditions on Earth, we suppose that they may occur similarly on Mars. The experimental alteration performed in the laboratory on alkaline Etnean basalts suggests that acidic conditions (pH values ranged between 3.5 and 5.0) and temperature ranged between 150°C and 175°C and acidic promote the clay neoformation. Therefore we can hypothesize that on the study area on Mars, the acidic conditions in a warm humid climate similar to the Mediterranean area on the Earth, may have been responsible for the clay formations, accelerating the time of formation.

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The Geoportal of the Sicily Regional Civil Protection Department: a precious tool for the managing of the territory

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Keywords: Civil Protection Department, Geoportal, SIT, webGIS.

The Geoportal of the Sicily Regional Civil Protection Department (DRPC SICILIA) (http://sit.protezionecivilesicilia.it) is aimed at the sharing out and the diffusion of the geographic information about the Civil Protection activities in Sicily. In more detail, the Geoportal provides data concerning all that territorial elements useful for the Regional System of Civil Protection. The project represents one of several initiatives carried out by the DRPC SICILIA in order to improve the System of Civil Protection by a tool, steadily available on-line, that supports both the activities of prevision and prevention of risks, and the management of the emergencies. The data, the geographic services and the metadata are published using the principles of cooperation and interoperability promoted by the INSPIRE Directive. Finally, the Geoportal allows the exchange of data between the institutional subjects, with the main goal of increase the territorial knowledge by awaken the citizens to the thematic of the Civil Protection.

The SIT (Sistema Informativo Territoriale – Territorial Informative System) platform is constituted by a centralized geodatabase, available in the form of a cartographic internet site (webGIS), that allow to see and manage the data using whatever client PC where they are not physically contained. The territorial information and services can be directly utilized by the client PC accessing to the different data levels of the server, with the possibility of download and afterward elaborate them. The graphic interface is very simple thus also inexperienced people can search and find the different required information in an intuitive way and/or using guided proceedings.

The geological data represent one of the most important content of the site. The results of the Seismic Microzonation studies carried out, along the eastern flank of Mt. Etna, as a consequence of the etnean seismic events of 2002 and, in the Catania, Messina, Siracusa and Ragusa districts, after the "Legge 77/2009" of the National Plan for seismic risk prevention, are reported. In particular, the microzonation studies of the etnean region have been inserted in the webGIS of the Regional Civil Protection Department. The map contents of the webGIS include the follow geographic, alphanumeric and documental data:

- Topographic maps with thematic characterization of the buildings (e.g. civil edifice, church, under construction edifice, etc.).
- Geological maps and cross-sections. This latter can be displayed clicking on the trace of the profile.
- Linear tectonic features such as fault and different types of fractures (e.g. historical coseismic, observed fractures related to the seismic events of 2002, etc.).
- Subsurface geological and geofisical data (stratigraphic logs and down-holes).
- Results of practicability of the edifices.
- Photographic documentation.

The webGIS section of the Geoportal is continuously uploaded by the publication of new data and projects of the Civil Protection.

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Mapping the rock matrix: formation and evolution of polyphase metamorphic basements

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Keywords: mineral assemblage, metamorphic stage, petrostructural fabric types, rock matrix.

Each metamorphic tectonite basically displays a dual property: the mineral assemblage related to a specific metamorphic stage and its expression into fabrics (e.g. coronite, tectonite, mylonite); both properties are, in time, subjected to changes. The metamorphic re-equilibration history may form **n** mineral assemblages, during metamorphic stages. Considering k fabric types (e.g. 3), $k*n$ different basic fabrics can appear. By the superposition of these basic fabrics, metamorphic stage after metamorphic stage, petrostructural fabric types (i.e. rocks) are produced. They are all the combination of basic fabric types of length $\leq n$ that each basic fabric can produce, with the restriction that the row index is strictly increasing. Each sequence produces k^m different petrostructural fabrics. The number of possible petrostructural fabrics after n metamorphic stages is then obtained by summing over m. We present mapping example of metamorphic basements where the relations between petrostructural fabric types are explained and the rock matrixx approach used.

SESSION S22

Morphodynamic processes at the seabed and in the Plio-Quaternary stratigraphic record of continental margins: georesources and potential geohazards

CONVENERS AND CHAIRPERSONS

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Eustatic and oceanographic control on sedimentary evolution of middle-late Quaternary shelf margin-to-upper slope deposits on the Egadi Islands offshore (Italy)

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Keywords: seismic stratigraphy, forced regression, contourite drift, Egadi islands.

During the past decades a number of sequence stratigraphy studies illustrated how, during Quaternary, interaction between sea level changes and sediment supply controlled the depositional evolution along continental margins, giving a cyclic signature to the sedimentary infilling. However, as both deposition and erosion are processes ultimately controlled by balance between environmental energy and sedimentary influx, also the oceanographic regime takes part in controlling the sedimentary growth along the continental margin. This is exactly what occurs on physiographic settings as islands offshore areas, where bottom currents can be very energetic.

In the western Sicily offshore, southwards of Egadi Islands, the sea floor is characterized by depositional and erosional features formed under a variety of sedimentary processes and offers opportunity to investigate as sea level change and oceanographic regime combine each other to control depositional evolution.

In this area, located along the clockwise flow of the Levantine Intermediate Water around the western Sicily margin, the sea floor morphology is very irregular as consequence of isolated reliefs and narrow submarine valleys, such as the Marettimo Valley which separates Favignana and Marettimo islands.

We analysed and interpreted a grid of high-resolution (1 kJ Sparker) seismic reflection profiles integrated with multibeam bathy-morphologic data of selected areas; a 270 cm long gravity core has been also collected for sedimentology and biostratigraphy.

The sedimentary succession accommodated along the eastern flank of the Marettimo Valley shows two different seismic units: unit A displays reflection-free seismic facies and thin, low- amplitude, inclined reflectors with downlap terminations onto the lower boundary, and erosional truncation at the upper boundary; these seismic facies are referable to oblique-tangential clinoforms and show a wedge-shaped external geometry. Unit B shows continuous, parallel, slightly concave reflectors and, towards the central sector of the Valley, continuous, sub-horizontal reflectors that form a deposit having a very broad low-mounded geometry; lateral transition in between concave and sub-horizontal reflectors is characterized by channelized erosional truncations.

The two seismic units can be interpreted as the sedimentary response of different depositional processes: unit A accumulated by progradation of shallow-water deposits during eustatic forced-regression; unit B is referable to contourite drifts deposited by bottom currents through the Marettimo Valley.

This unusual interbedding of very shallow water contouritic and shelf margin deposits derives from enhanced sedimentary dynamics during sea-level fall and lowstand stages when, as consequence of decreased water depth of the Marettimo Valley, bottom currents accelerated scouring channelized erosional surfaces; in the same time, deposition of forced regression across the shelf margin buried contourite drifts.

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Seismotectonics and seismostratigraphy of the northern Sicily-southern Tyrrhenian seismogenic belt: new constraints for seismic hazard assessment

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Keywords: seismic reflection, seismogenic structures, neotectonics.

Northern Sicily and its offshore are a transitional area between the Sicilian–Maghrebian fold-and-thrust belt (FTB) to the south, and the Tyrrhenian back-arc basin, to the north. This hinge area, corresponding to both the outcropping and the submerged part of the chain, is characterized by an intense instrumental seismicity, medium to low magnitude (Montone et al., 1999), and by historical earthquakes. The available focal mechanisms (e.g., Vannucci and Gasperini, 2004) show a still active compressive stress field with minor strike-slip components (Pondrelli et al., 2006); on the contrary, Giunta et al. (2009) interpreted the extensive seismic activity as due to both synthetic right-lateral, NW-SE/E-W oriented, and antithetic left-lateral, N-S/NE-SW oriented, strike–slip fault systems. So, the active and possibly seismogenic tectonics of the FTB in Quaternary times is still debated.

Aiming to define the active deformational pattern and the relationships with the regional geodynamics and seismicity along the northern Sicily-southern Tyrrhenian seismogenic belt, we interpreted a dense grid of different resolution/penetration seismic reflection profiles, including multichannel seismic lines on land. In the marine areas, multibeam data were used to correlate the recent tectonic elements, identified as potentially active seismogenic sources, with morphological features at the seabed.

Differently oriented neotectonic features have been recognized all along the continental margin. Strike- and dip-slip faults, with a dominant ENE-WSW orientation, mainly control the uneven shape of the northern Sicily margin. Some of them appear to be reactivated in the frame of a contractional stress field. Comparing these results with the available seismological data, we identified a fault system with kinematics and geometry consistent with the distribution of the seismic sequences recorded in the region. We hypothesize that these structures should be still active and potentially responsible for the shallow seismicity of the study area.

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Identification of diachronic erosional surfaces related to the Middle - Late Pleistocene glacioeustatic fluctuation to time-constrain volcanoclastic and geological events in the Campania-Latium offshore. Interaction between tectonics, volcanism and eustatic variation

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Keywords: seismostratigraphy.

This study aims to reconstruct the geological evolution of the Campanian-Latium continental margin in the Gulf of Gaeta sector (central-southern Tyrrhenian Sea) during the Quaternary, throughout the interpretation of high-resolution seismic profiles, with a penetration of 0,5 s/TWT, acquired with sonar CHIRP in the frame of the CARG project and of a 7 m –long gravity core (Margaritelli et al., 2016). The stratigraphic record of the Tyrrhenian margin is influenced by the combination of both global and regional-local processes: the Pleistocene glacial-eustatic fluctuations; tectonics, volcanism and volcano-tectonics; subsidence vs. uplift; the sediment supply from the Garigliano and Volturno rivers; erosion processes related to the marine circulation. The Late Pliocene to Recent extensional tectonics, responsible for the southern Apennines uplift, conditioned, together with the intense volcanic activity (Roccamonfina, Vesuvius, Campi Flegrei volcanic sites), both the present-day morphology of the margin and the marine and continental sedimentation of coastal plains, up to 3000 meters thick in the Volturno plain (Ortolani and Torre, 1981; Torrente & Milia, 2013). Seismostratigraphic analysis highlights the erosional surface of the last glacial maximum (LGM), corresponding to the MIS 2, and dating back about 25 ka. The erosional surfaces related to the MIS 6.2 (140 ka) and MIS 8.2 (245 ka) were also identified. These surfaces were used as chronostratigraphic reference[RD1] to age-date volcano-tectonic events (extensional and transtensive faults) and related products (erosional and depositional features, as gravity flows and submarine landslides, phases of hydrothermal fluids rising), occurred in this sector of the Campanian-Latium margin during the last 250 ky.

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Comparing present-day and relict coastal wedges along the continental margin off Campania; geographical exposure and geological setting

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Keywords: Infralittoral Prograding Wedges (IPW), Submarine Depositional Terraces (SDT), continental shelves.

There has been renewed attention on present-day and relict submerged coastal wedges (Infralittoral Prograding Wedges, IPW, Hernandez-Molina et al., 2000 and Submerged Depositional Terraces, SDT Chiocci and Orlando, 1996) in the last years, mainly to assess their reliability as environmental indicators or morphological proxies of past sea level stands. The leading upshots of the debate are: 1) the edge depth of present-day coastal wedges is highly variable and generally found between 10-30 m b.s.l., depending on the exposure of the coastline and the regional storm wave climate; 2) a likely inaccuracy of at least +/-5 m might be computed when measuring the depth of the rollover point both from seismics and Digital Elevation Models (DEM); 3) once formed, the edge depth of time-constrained and well-preserved SDT can be used to evaluate the post-depositional net vertical displacement of the substratus (Pepe et al., 2014; Casalbore et al., 2016).

This study consists of a census of about 60 IPW, along the Campania offshore, in order to gauge their quote on the regional scale and verify the relation of the rollover point depths versus their geographical exposure. A combined data set of DEM, high-resolution seismic profiles and gravity cores has been used to recognise the depth, the shape and the extension of present-day IPW and, by application of the actualistic model, their ancient counterparts, developed during the Last Glacial Maximum, off Punta Licosa (Salerno Gulf). This area is tectonically stable since MIS 5e. Here, a 20 km-wide shelf-edge SDT, with its associated backward marine abrasion platforms, has been recognised at the seabed and locally cored. Preliminary results have evidenced that IPW are mostly ubiquitous features off wave-dominated and sediment-starved coasts, alluvial/estuarine coastal plains with high sediment yield, as well as shielded inlets; their shape may differ consistently among the different settings. The observed shelf-edge SDT rollover depth at about -140 m (20 +/- 5 m paleo-bathymetry) is compatible with the present-day scenario along the south-westward exposed coasts.

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Activation versus de-activation of a Pleistocene turbidite system in response to major volcanic events: the example of the Dohrn canyon-fan system in the continental slope off the Campania region (Southern Tyrrhenian Sea, Italy)

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Keywords: Canyon thalweg, Digital Elevation Model (DEM), continental margin, volcanoclastic supply.

The role of intense explosive volcanic activity and volcanoclastic yield in the activation/deactivation of a turbidite system can be evaluated along the continental margin of Campania region (Tyrrhenian Sea - Italy), where three wide canyon-fan systems occur at short distances ones to another. Actually, the Dohrn, Magnaghi and Cuma canyons cut the continental shelf and slope off Ischia and Procida volcanic islands and off the Campania Plain where the active vents of Campi Flegrei and Mt. Vesuvius are located.

This research is based on single-channel high-resolution seismic profiles (Sparker-One 16 kJ, 0.5 s twtt), swath-bathymetry and litho- and tephra-stratigraphy from gravity cores. We focussed on the stratigraphic position of paleo-thalweg features and channel/levees deposits in seismic records, debris flow, turbidites and hemipelagites in cores, to learn more on the activation/deactivation stages of the Canyon Dohrn, in the frame of relative eustatic sea level variations over the Middle Pleistocene-Holocene time span.

Preliminary outcomes suggest that even major volcanic events, such as ignimbrite eruptions or large fallouts, whose magnitude might have exceeded 180 km^3 DRE (e.g. Campanian Ignimbrite; Costa et al., 2012), have caused the infilling of the canyon head and the cover of pre-existing seabed topography. As a consequence, the temporary deactivation of the turbidite system occurred, despite the volcano-clastic overload in the coastal environment (Roca, 2015). Phases of renewed activities along the thalweg are observed, both in cores and seismics, to be in step with the falling stages of sea level, which have driven the re-incision of the canyon valley throughout the intermittent passage of coarse-loaded downflows. The occurrence of volcanoclastic debris flows and turbidites is documented in cores and tells of effective sedimentary bypass from source areas to basin fan. Presently, we observe the quiescence of the Dohrn Canyon despite the intense Holocene volcano-tectonic activity in the area.

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Seafloor waveforms in submarine volcanic setting as proxy of active sedimentary dynamics

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Keywords: cyclic steps, sedimentary gravity flows, slope break, multibeam bathymetry.

High-resolution morpho-bathymetric and side scan sonar data collected in the central and eastern part of the Aeolian volcanic arc (Southern Tyrrhenian Sea) depict widespread waveforms on their volcaniclastic aprons from shallow-water sectors up to 3.200 m water depth (Casalbore et al., 2014). These features are characterized by an high variability in wave parameters (wavelength of 30–1600 m and wave height of 1–200 m), plan-view morphology (from sinuous to crescentic) and cross-section (from undulating to stepped), indicating that different sedimentary processes, at variable spatial and temporal scale, are responsible for their formation. By relating the morphological characters of the different waveforms with the local boundary conditions (morphological setting, regional slope gradients, sediment source and dynamics), we try to better constrain the factors controlling their formation. For instance, some of these features occur at the seabed just below a marked decrease of slope gradients, and could be interpreted as cyclic steps, i.e. a class of class of slow upslope migrating turbiditic sediment waves, where each downward step is bounded by a hydraulic jump. By comparing the morphometric characteristics of the recognized waveforms with the results of experimental evidence and numerical modeling proposed in literature, we attempt to test if they can be generated as cyclic steps and, more in general, discuss what the waveforms characteristics may tell us about the sediment dispersal and the nature of the flows that generated them. Some small-scale waveforms showed significant morphologic variations (i.e. upslope migration) on repeated multibeam surveys at the 10-year scale, indicating that they are due to active morphodynamic processes.

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Erosive and depositional processes on shelf prodeltaic deposits linked to a "Fiumara" river in the Gulf of Patti (NE Sicilian margin)

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Keywords: gully, seafloor waveforms, hyperpycnal flow.

The NE Sicilian continental margin formed as a rifted margin in relation to the opening of the Tyrrhenian back-arc basin. This area is affected by regional uplift at rates in the order of ca. 1 mm/a since Pleistocene, with higher local uplift associated with co-seismic vertical movements. Because of the rapid uplift, several short "fiumara" rivers with steep course deeply incise the coastal highlands. This kind of rivers typically go through seasonal periods of dry stream bed that alternate with short intervals of water supply during intense flash floods. During these events, the large amount of sediment and debris released at the river mouth possibly evolves into marine hyperpycnal flows. If the continental shelf is absent or dismantled by canyon heads, hyperpycnal flows are directly funneled into the upper slope. On the contrary, if a larger continental shelf is present, these flow can form linguoid or lobate deltaic system. In this study, we present the first results of an integrated analysis of high resolution multibeam bathymetry, backscatter, seismic data and seafoor sampling recently collected on the prodeltaic system developed off the mouth of Mazzarrà Fiumara (Gulf of Patti). Particular attention will be dedicated to constraint the genesis of seafloor waveforms and gullies that morphologically characterizes this prodeltaic system by using their morphometric parameters and comparison with similar study elsewhere. We also attempt to reconstruct the relationship between the observed erosional and depositional features on the background of the manifold processes that may have contributed to the stratigraphic growth and geomorphic shaping of this deltaic system.

Morphodynamic processes and marine geohazards assessment in the Ionian Calabrian continental margin

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Keywords: Morphodynamic, morpho-bathymetry, sub-bottom profiles, marine geohazards, Ionian Calabian margin.

The Ionian Calabrian Margin (ICM) is a tectonically-active margin resulting from two main processes: frontal compression and fore-arc extension during the SE advance of the Calabrian accretionary prism since late Miocene; and rapid uplift of onshore and shelf areas since mid-Pleistocene. These processes have directly or indirectly influenced all morphological features observed at seabed. In this study, we integrate multibeam morpho-bathymetric data acquired by OGS in water depths of 150–2000 m with subbottom profiles in order to map major seabed features of mass movement on the slopes of the ICM and consider possible triggering mechanisms.

Four main types of mass movement phenomena are recognized along the ICM:

1) mass transport complexes within intra-slope basins –in the northern area, seabed imagery show the slopes of seabed structural highs to be marked by headwall scarps recording widespread failures, while subbottom profiles show the adjacent basins to contain unstratified bodies indicative of debris flows buried beneath stratified sediments, recording one or more episodes of failure.

2) isolated slides –along the relatively steep southern slope, seabed slide scars and stacked subsurface slide deposits record a history of episodic slope failure.

3) gravity sliding – on the southern slope, elongate seabed features oriented subparallel to contours are observed associated with diapiric structures linked to Messinian salt, and may record a form of downslope sediment creep.

4) headward retrogressive canyon activity– the canyons incising the southern slope of the ICM margin show numerous headwall scarps and morphologies that are consistent with retrogressive activity of the canyons.

Multiple slides, downslope creep and canyon retrogression along the southern slope of the ICM may all be a response to differential uplift of Calabria since the mid-Pleistocene. However, seismic triggering cannot be excluded, and is the likely cause of multiple failures along fault-bounded structural highs in the north.

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Evolution of the coastal barrier-lagoon system offshore Cabo-Frio – Rio de Campos (E-Brazil) during the late Quaternary transgression

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Keywords: Brasil continental shelf, late Quaternary sea level rise, relict barrier.

Coastal barrier-lagoon systems are dynamic environments of great economic and ecological importance, but also of great sensitivity to climate change and sea level rise. The continental shelf offshore East Brazil is relatively poorly studied, which prevents detailed reconstruction of the geomorphologic development during the late Pleistocene-Holocene transgression. Here we present a morphologic and stratigraphic analysis of the Late Quaternary barrier-lagoon systems offshore Cabo Frio and Rio de Campos, using 150 km of high resolution seismic data (Parasound echosounder) and Multibeam bathymetry (Kongsberg EM 710), as well as intermittent core sampling acquired during cruise M125 by the research vessel Meteor in March/April 2016. The broad (~80 km) continental shelf has a low depth gradient, high wave energy and is sediment starved. At present, sedimentation is strongly drift dominated, with mostly bioclastic outer shelf and siliciclastic inner shelf deposition. The main morphological features include several relict barriers along most of the shelf, aligned over at least three levels in a bathymetric range from 60 to 85 m depth. The stratigraphy is characterized by a recent thin sandy drape overlying several seismo-stratigraphic units representing coastal prograding wedges, coastal barriers and broad back-barrier lagoon and/or channel systems. The back-stepping of river channel deposits is overlain by coastal back-barrier lagoon deposits, following sea level rise. This observation indicates that the stratigraphic evolution of the shelf was dominated by a late Pleistocene - Holocene transgressive ravinement. The interplay between the rate of sea level rise, the geomorphologic setting and the preservation potential of former shorelines, is compatible with the current coastal morphology of the on-land area. The evolution of such submerged coastal systems is compared to other submerged settings studied worldwide with the scope of improving late Quaternary sea level rise models.

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Allogenic vs. autogenic controls on turbidite systems erosional behaviour: an example from the Capo Ferrata turbidite system (Eastern Sardinian Margin)

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Keywords: Canyon, leveed channel, terraces, channel avulsion, megascour, transient fan.

Turbidite systems are often affected by alternating erosional and depositional phases that are the major control on geomorphic element development (Bouma, 2004; Brothers et al., 2013). In particular, when erosional processes prevail a general entrenchment of the system is accompanied by the development of erosional features with different hierarchy. Their dimension and temporal extent are directly influenced by the variability of the factors that control the turbidite systems evolution (Peakall & Sumner, 2015). In this study, multibeam bathymetric data has been used in the study of the erosional features in the canyon and channel-levee area of the modern Capo Ferrata turbidite system, in the Sarrabus Intraslope Basin (Eastern Sardinian Margin). It represents an example of a transient fan linked through the Sarrabus Canyon to a deeper base level in the Vavilov Basin. The Capo Ferrata system is affected mainly by net-erosional processes that shape both the canyon and channel system and their adjacent slope and levee areas. In the shallow water area, strong erosional processes are shown by the indentation of the canyons heads up to 2.4 km landward from the shelf-break. Further downslope, the erosional action of turbidity currents is enlightened by the presence of scours and plunge pools in coincidence with gradient changes along the channel floor. In particular, the coalescence of several scours leads to the development of a megascour, identified as an embryonic thalweg. The canyon and channel areas have been also affected by the lateral migration of the meandering thalweg, that led to meander cutoff and channel avulsion. As a consequence, erosional morphologies such as terraces and arcuate shaped features formed along the channel flank. Furthermore, an abandoned channel tract related to the northward shift of the thalweg has been identified. The shift of the thalweg was influenced by the morphologic setting of the area, developing in the depressed area comprised between the abandoned thalweg and the southern levee of the northern turbidite system. The prevalence of erosion over deposition has been attributed to the influence of eustatic cycles and to the non-equilibrium of the transient turbidite system profile due to the presence of a base level deeper than that of the depositional lobe.

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3D Tsunami modelling from submarine landslide in Gulf of Naples, Southern Tyrrhenian Sea, Italy

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Keywords: tsunami, geohazards, Gulf of Naples.

In this study, we propose a 3D numerical modeling of tsunami waves generated by an underwater landslide. The simulated gravity instability is located in the Gulf of Naples near the head of the Dohrn Canyon. The availability of a detailed bathymetric map both with a good knowledge of the local geology allowed us to obtain reliable simulation results.

The Dohrn and Magnaghi canyons are controlled by the interaction between volcanic activity (Phlegrean Fields and Ischia and Procida volcanic complexes) and sedimentary processes related to the Sarno and Sebeto rivers. Despite the canyon system is actually inactive, the main submarine instabilities have been identified and mapped around the Dohrn western branch, from the head to the middle of the branch, on the continental slope southwards of the Magnaghi canyon and on the north-western slope of the Banco di Fuori carbonatic high.

A modified version of the GEOWAVE (Watts, 2009) model is used, taking properly into account the decreasing nearshore tsunami wavelength through a system of nested grids. GEOWAVE simulates tsunami waves generation, propagation, and inundation using a fourth order fully nonlinear equations, fully dispersive Boussinesq wave model with multiple wave dissipation mechanisms, wave breaking, and dry land overflow. In the numerical simulation, the Tsunami Open and Progressive Initial Conditions System (TOPICS) is adopted to produce 3D tsunami source for tsunamis generated by submarine slides and slumps, while a 25 m uniform spacing grid is derived from the bathymetric dataset of the Naples Bay.

Interesting results of tsunami simulation, in the above-mentioned areas, show that the amplitude of wave run-up ranges from 0.90 m near to Procida Island and up to 1.90m nearness of Naples Port. This difference in run-up is ascribed to a different coastal morphology. In fact, the port of Naples offshore has a slope of 3-4 degrees while the Procida Island offshore of 25-30 degrees.

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Onshore to offshore stratigraphic-structural correlation in the north-eastern Lampedusa area (Sicily Channel, Mediterranean sea)

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Keywords: Lampedusa Island, seismic profiles, multibeam, lithostratigraphy, structural measurements.

The Pelagian Archipelago (Lampedusa, Lampione and Linosa) is located in a complex and wide geodynamic system characterized by the occurrence of two independent tectonic processes acting simultaneously (Corti et al., 2006 and references therein): convergence along the Apennine-Maghrebian accretionary wedge and rifting in the Sicily Channel (Giunta et al., 2000). Through high resolution single-channel seismic reflection profiles (Sparker) acquired on July 2015 in the offshore of the Lampedusa Island, we aim to define in detail the late Miocene-Pleistocene stratigraphic and structural evolution of this sector of the Pelagian Archipelago. In particular, we focus on the northeastern sector of Lampedusa, where onshore stratigraphic-structural measurements are available (Baldassini et al., 2015). The onshore-offshore correlation will enhance the current geodynamic and paleogeographic knowledge on the Lampedusa area (Grasso & Pedley, 1985; Torelli et al., 1995). The dataset consists of a grid of 21 seismic profiles for a total length of about 140 km. The preliminary analysis of seismic data highlights a well-defined post-Tortonian erosive truncation here interpreted as an unconformity separating the Lampedusa Formation from sub-horizontal Pleistocene to Holocene deposits (Grasso & Pedley, 1985), which are characterized by bedforms, erosional features and diapirs. The onshore sediments are represented by shallow water bioclastic grainstones and carbonate lithoclast breccias, ranging in thickness between 10 and 30 m. Furthermore, the high resolution of the seismic profiles allows us to better define the offshore prosecution and activity of the most important tectonic structure recognized onland, the Cala Creta fault. The latter appears inactive at least from the Pliocene and shows late Miocene syn-sedimentary transtensional deformation, as also shown by Torelli et al. (1995 and references therein).

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Slope instability and erosional features of the Ligurian Margin

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Keywords: Ligurian Sea, Seafloor morphology, Seismostratigraphy, Submarine landslides, Submarine Canyons.

The recent conclusion of the Magic Project (Marine Geohazards along the Italian Coasts) (Chiocci & Ridente, 2011), the MALISAR Cruises (Migeon et. Al., 2011; Migeon et al., 2012) and the contribution of the data available at the Universities of Genoa (IT) and Trieste (IT) allowed us to identify and study the large series of erosional and gravitative phenomena along the Ligurian continental margins. The dataset allowed us to relate the structural evolution of the Ligurian Basin, the characteristics of the sedimentation, the erosive action of a dense canyon network and the gravitational phenomena (Corradi et al., 2002).

The Ligurian Sea is the northwestern portion of the Mediterranean Sea. It originated from the roto-translation of the Corsica-Sardinia Block and is connected to the Apennine orogenic dynamics (Fanucci & Morelli, 2000). The complex geological evolution of the Liguran Sea brought to the division of this basin in different physiographic domains. The main one is the Valley of Genoa that separates the margin of the Alpine area from the Apennines one, which developped in a portion of the newly formed chain. The evolution of the two margins, mainly controlled by extensional tectonics processes, was interrupted by compressional and/or transpressive reactivations, which gave particular characteristics to the margins (Fanucci & Morelli, 2013; Sage et al., 2013; Sage et al., 2014).

The Alpine margin is characterized by high seismicity, high sedimention rate and steepness of the margin, determining massive and unstable sedimentary masses along the slope, which are carved by a dense network of canyons.

It is in the western Liguria sector that these erosive features are extensively represented until the "Dorsal of Imperia", a structural element that runs parallel to the margin for about 50-60 kilometers. Its genesis can be attributed to the effects of a compressive deformation and this structure isolated an intra-slope basin in which huge quantities of sediments were accumulated and drained by canyons and conveyed in the Valley of Genoa, through the Canyon of Vado.

The continental margin between the City of Genoa and the Portofino Promontory is characterized by the two main canyons of the Ligurian Gulf: the Polcevera and the Bisagno canyons. These are in continuity with their respective rivers and almost entirely eroded a thick Plio-Quaternary sequence.

The Apennine margin presents a less complex structure than the Alpine one (Fanucci & Morelli, 2006); however, large gravitative phenomena are present. The most important is the Portofino Landslide, located in front of the corresponding promontory. It is mainly characterized by rotational slips and incipient detachment niches, stimulated by the erosion at the base by the Levante Canyon. This last, oriented along the Apennine tectonic lineations, produces significant erosion, both on the head than along its way, which is almost parallel to the coast until its confluence in the Bisagno Canyon.

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Offshore active fault system and sedimentation in the Al Hoceima region from new high-resolution bathymetric and seismic reflection data

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Keywords: bathymetry, seismic reflection, tectonics, seismicity, Nekor basin, Trans Alboran Shear.

The Alboran Sea, located in the westernmost alpine Mediterranean belt, forms the main Neogene-Quaternary basin of the Betic-Rif Cordillera. Deformation since the Late Miocene provides evidence for the initial stages of collision tectonics, accommodating the present-day NW-SE oblique convergence of the Eurasian and African plates. For the last 10 years, Spanish, Moroccan, Italian, and French institutions have been conducting collaborative investigations around the Trans Alboran shear zone (TASZ) and the Al-Hoceima Region (Morocco), one of the most active seismic areas of the western Mediterranean Sea. High-resolution seismic reflection and swath-bathymetry data from the Marlboro 1 cruise in 2011, the Marlboro-2 cruise, and the Eurofleet campaign Saras in 2012, were used to detail the active fault and fold systems and associated sedimentary features. Signs of both past and present strong tectonic deformation, submarine landslides, and contour structures were observed and are described in detail. The consequence of the inversion of the Alboran basin, the TASZ, an active crustal scale fault zone, is made of a main set of NNE-SSW sinistral and WNW-ESE dextral conjugate faults forming an angle close to 75º surrounding a rigid basement tectonic block connected to the African plate and representing the origin of most of the shallow seismicity of the central Alboran Sea. Sedimentary features such as submarine mass transport deposits (MTDs) and contour structures were observed along downslope submarine compressive structures associated with this active deformation, on both sides of the Trans Alboran Shear Zone (TASZ) and the Alboran ridge. In the distal margin off Morocco, on the two flanks of the Xauen/Tofino and South Alboran ridge, the sedimentary architecture affected by growth-faults is mainly composed of contourites. Internal strata patterns, spatial and temporal distribution of thickness and depocenters, and discontinuities help to infer sedimentary processes and their interaction with tectonics. In the southern Alboran Sea where the bathymetry shows abrupt slopes, the recurrent seismic activity (as demonstrated by the 1994, 2004 and 2016 recent earthquakes) could induced mass wasting. The mass transport complexes (MTCs) originate from escarpments on the edge of the contourites. However, in most cases, the seismic reflection data show the depositional bodies of numerous slides and giant slides linked to the activity of growth-faults and thrusts observed on the Xauen-Tofino Bank's and Frances Pages seamount north flanks. We propose that tectonic activity influences the growth of contour structures and, along with seismicity, may trigger mass transport deposits (MTDs). These interpretations were confirmed during the INCRISIS campaign this year in the same area in, revealing new occurrence of MTDs during the seismicity crisis that has been underway since the end of 2015 in the Alboran sea. At the southern part of the TASZ, the seismically active Nekor basin is an extensional basin formed in a convergent setting. Its boundaries extend both onshore and offshore Morocco. In addition to a morpho-tectonic map in the deep setting, detailed surveys in a shallow water environment have allowed to identify the connecting onshore-offshore active structures and to propose a complete tectonic framework including the near coast offshore Al Hoceima, north Morocco and the study of the fault system through the Nekor basin, between the Trougout Fault and the Boussekour Agdal fault. Active faults affect sedimentary structures above related to the last sea-level fall sometime producing a vertical offset of more than 10 m at the sea-floor. Inactive Plio-Quaternary normal faults to the east of the Ras Tarf promontory and geometries of depocentres seem to indicate the migration of deformation from east to west during the Pliocene-Quaternary. The tectonic activity migrates from the Boudinar basin to the Nekor basin with the progressive abandoning of eastern structures.

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Fine-scale distribution of coralligenous and maërl habitats off the western Pontine Archipelago (central-Tyrrhenian Sea)

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Keywords: Coralligenous and maërl ecosystems, Pontine Archipelago, Tyrrhenian Sea.

Coralligenous and maërl habitats are considered the most important ecosystems in the Mediterranean Sea, representing a key spot of biodiversity (Ballesteros E., 2006). Moreover, coralligenous habitats are used as benthic indicators to guide progress towards achieving Good Environmental Status in marine waters by 2020 (European Commission, 2008).

In this study, an area of about 25 km^2 located off Zannone Island (western Pontine Archipelago) was investigated by means of multibeam data (bathymetry and backscatter), video observations and sediment sampling in order to define the fine-scale distribution of maërl and coralligeneous habitats. The integrated analysis of acoustic and video data allowed us to recognize different seafloor types: flat areas associated with low or absent bioclastic sandy sediment; areas associated with coralligenous concretions and/or high bioclastic sandy sediment (maërl/rhodolithes); sub-flat areas associated with bioclastic and/or terrigenous sandy sediments; areas associated to substrate outcrops. Detection of anthropogenic impacts was also evaluated.

Moreover, coralline algae were analyzed by means of scanning electron microscope images in order to identify the main species inhabit in the study area (e.g. *Lithothamnion coralliodes* and *Lithothamnion valens*). The abundance of the main morphotypes recognized (maërl, praline, boxwork) and the abundance of live rhodolithes has been determined in the collected grab samples.

Preliminary results indicate that the study area is extensively colonized by living rhodolithes with a complex distribution, including sectors where living rhodolithes reach 90% of abundance. This result confirms that wide sectors of the seafloor surrounding the western Pontine Archipelago host these precious habitats (Bracchi and Basso, 2012; Sané et al., in press).

The achievement of this study provides an example on fine-scale distribution of both coralligenous and maërl habitats for the Mediterranean Sea, proving how the combination of remote sensing (backscatter) mapping and video observation is essential to realise an effective monitoring of such complex and variable environment, in view of assessment of environmental status and/or the management of marine protected areas.

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Upslope vs downslope asymmetric bedforms evidence complex oceanographic patterns at the head of a submarine canyon

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Keywords: Asymmetric sandwaves, megaripples, submarine canyon, AUV seafloor mapping, internal tide fluxes.

Sedimentary flows from shelf to deep ocean are generally controlled by gravitational flows, but their patterns can become more complex in the vicinity of submarine canyons. Here we document uncommon asymmetric bedforms that are interpreted to be the geomorphic expression of both upslope and downslope flows connecting the upper reaches of the Whittard Canyon to the outer shelf on the northern Biscay margin. During the JC125 CODEMAP expedition, funded by ERC Starting Grant 258482, high-resolution data were collected from two 7 km apart sandwave fields along the outer shelf adjacent to the head of Whittard Canyon. Data include AUV sidescan sonar (0.15 m res), 3 ROV-mounted vibrocores, 2 box cores, 2 shipboard MBES bathymetry (5 m res) collected 15 years apart and sub-bottom profiles, allowing a multi-resolution analysis of the mapped bedforms in both space and time. The sandwave fields occur at 170-220 m depth, and display wavelengths ranging from 300 to 700 m and wave heights of 3 to 8 m. One field of well-developed sandwaves has an unusually pronounced upslope asymmetry, facing the shallower regions of the shelf. Contrastingly, the second sandwave field has similar morphometric characteristics but shows a downslope asymmetry, facing the head of the canyon. AUV sidescan sonar mosaics show with unprecedented quality spectacular trains of fresh megaripples with an average wavelength of 10 m, overprinting the large sandwaves. The megaripples reflect the same asymmetric trends, suggesting a constant hydrodynamic regime in the region. AUV-derived images also show unusual lenticular features along the wave crests, which have not been described previously.

Despite the low migration rates inferred from the comparison of the bathymetric datasets, differences in sediment grain size and composition between crests and troughs confirm that the crests are controlled by active processes. The spatially variable regime of the internal tide may be one of the mechanisms involved in the generation and maintenance of the mapped sandwaves. Concurrent hydrographic observations within the canyon using an autonomous ocean glider indicate large-amplitude semidiurnal internal tides are present, possibly transitioning to asymmetrical-shaped internal bores in the upper reaches. Moreover, preliminary results from a numerical model of the semidiurnal internal tide within the canyon suggest a dynamic environment with internal tide energy fluxes directed both up- and down-canyon. This work highlights the local importance of uncommon and still not fully characterized sedimentary dynamics, which are likely related to a complex interaction between canyon morphologies and tidally-driven oceanographic regimes. These results challenge traditional notions of gravity-driven processes being dominant in canyon head environments, and have implications for geo-hazard assessment of mobile substrates in outer shelf settings and quantification of offshore sediment and carbon fluxes.

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Bathy-morphological analysis of submarine canyons across the north-western Sicily continental slope

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Keywords: submarine canyon, morphobatymetric analysis, northwestern Sicily margin.

We present here the results of the morpho-bathymetric analyses of the main submarine canyons along the upper slope off the north-western Sicily. This region developed during the Neogene as the transition area between the Sicilian fold and thrust belt and the Tyrrhenian basin realm. Along the upper slope, a dense network of submarine canyon develops from 80 m water depth up to more than 2000 m, showing a large variability of sizes and morphology. In this area submarine canyons play a crucial role related to the along-slope sedimentary transport and are among the most distinctive features of the submarine seascape.

This study is based on a quantitative analysis of a high resolution multibeam data set of the north-western Sicily offshore integrated with the topographic DEM of the adjacent continental region. Very different canyon-related morphological features along the study area mainly suggest the occurrence of top-down gravitational processes along canyons likely originated through a bottom-up evolution. By means of high resolution bathymetric data, we: i) described the main morphological features of submarine canyons; ii) measured the main morphometric parameters along canyon longitudinal profiles; iii) calculated the extension of different lithology outcropping on the river catchment areas corresponding to distinct river-fed canyons. For each analyzed canyon a chart was built in which bathymetric longitudinal profile, catchment area extension and gradient longitudinal profile have been reported.

Quantitative analyses of longitudinal profiles reveal that the morpho-sedimentary evolution of mapped canyons is comparable to the corresponding fluvial environment, although presenting some differences.

Integrated analysis of offshore data and river catchment areas suggest that the continental slope structural setting as well as the outcropping lithologies could be relevant control factors on the morpho-sedimentary evolution of the NW Sicilian canyons.

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Sedimentology of supercritical-flow features preserved in the lower Pleistocene deltaic succession of the Messina Strait (Calabria, Italy)

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Keywords: Lower Pleistocene, fan-delta, Messina Strait, supercritical flows, facies analysis, scour-and-fill structures.

Supercritical flows entering marine shallow- and deep-sea settings have greatly stimulated researchers from all over the world. Terminologies like 'cyclic steps', 'backsets', 'antidunes' etc. have recently received more attention, because associable to supercritical current regimes, whose sedimentary product is retained virtually unperceivable in the rock record. Observations in modern environments have pointed out the important role of supercritical flows in deep-marine systems, as they can explain a number of features detectable in ancient turbidites. Fewer case studies have instead documented the effects of high-energy flow entering shallow-marine settings and correspondent examples from the rock record are very scarce.

In this presentation, the results of a facies-based study carried on a spectacular outcrop exposed along the northern border of the Messina Strait, between Calabria and Sicily, are provided. The aim is try to investigate the nature of the scour-and-fill structures preserved into discrete horizons belonging to a fan-delta complex, suggesting river-dominated supercritical flows as possible main interpretation.

The studied deposits are early Pleistocene and unconformably back-step against the basement of the Calabrian Arc. A 230-m-thick sand body is bounded landward by a NE-SW-trending fault, whereas it thins towards W-NW (seaward) over ca. 1,5 km. Two main vertically-stacked intervals can be detected: (i) a lowermost interval consists of basal conglomerates and pebbly sandstones, including out-size basement blocks and shell fragments, for a total thickness of ca. 90 m; (ii) an overlying bioclastic-rich sandstone interval exhibits cross-strata and large-scale tidal foresets, for a total thickness of ca. 140 m.

The lowermost interval reveals a set of cross-cutting master erosional surfaces with very irregular morphology, bounding pebbly and shelly sandstones including large-scale cross stratification, showing both seaward and landward foreset dips. Internally, a series of minor *en-echelon* spoon-shaped erosional surfaces, filled or draped by foresets pointing in a landward direction occur, as well as remnants of tidal cross strata-sets.

These two intervals are interpreted as the result of the initial progradation of a river-dominated fan delta, impinging the Messina Strait during the early Pleistocene and turning into a tide-influenced delta after a dramatic phase of tectonically-induced transgression. The scour-and-fill features detected in the lowermost interval are referred to the effect of violent river-generated flash floods entering a shallowly-submerged basin margin and generating supercritical-flow structures. These features are here described and discussed in order to provide a field-based example from a shallow-marine ancient case study.

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Recent submarine landslides on the continental slope of Storfjorden and Kveithola Trough-Mouth Fans (north west Barents Sea)

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Keywords: Arctic, submarine landslides, meltwater, LGM, slope stability.

Up to twelve submarine landslides retain a morphological evidence as concave amphitheater-like depressions of various sizes on the middle and upper slope of the Storfjorden and Kveithola Trough-Mouth Fans (TMFs), NW Barents Sea. The largest of them show lateral scarps 35-40 m high that reach the continental shelf edge and cover an area of at least 1120 km^2. Submarine landslides are translational, with headwall and laterals scarps clearly cut into Last Glacial Maximum debris flows deposits. The largest landslides seem to be rooted at the base of a terrigenous/hemipelagic sedimentary unit inferred to be of Middle Weichselian age (Marine Isotopic Stage 3). Stratigraphic, lithological and geotecnical observations suggest that the the rapid deposition of a thick sequence of fine-grained, high water content interlaminate plumites is the most important controlling factors in the generation of submarine landslides on the southern Storfjorden and Kveithola TMFs.

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Quaternary stratal architecture of Southern Latium and Northern Campania continental margins

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Keywords: Continental shelf, seismic stratigraphy, sea-level variations, Quaternary, eastern Tyrrhenian margin.

A dense network of high-resolution reflection seismic profiles allowed us to reconstruct in detail the stratigraphic architecture of the Tyrrhenian margin from Capo Circeo to Ischia Island (central Tyrrhenian Sea).

The area is characterised by an overall stratigraphic setting similar to all the other Quaternary margins worldwide, where the marked sea-level changes due to Milankovitch glacio-eustacy cycles produced 4th-order depositional sequences. The sequences mark up the progradation of the continental margin that basically occurred during the prolonged phases of sea-level fall during the strongly asymmetric Quaternary sea-level oscillations (fall ~100 m in ~100 kyr, rise ~100 m in ~10 kyr). Therefore the Quaternary deposits are made up mainly by FSSTs and locally by LST, locally represented by small prograding sedimentary wedges (submerged depositional terraces, SDTs): both are truncated at their top by regional erosional unconformity formed during the Last Glacial Maximum (MIS 2) and reworked during the following sea-level rise.

The detailed seismostratigraphic analysis of the very dense network of single channel seismic profile (average 1.02 km/km^2) allowed to recognise up to 9 unconformities and correlative conformities bounding the depositional sequences. The growth pattern of these sequences is influenced by the presence of structural highs that are made-up of meso-cenozoic basement or Miocenic units. In detail, the sequences reach the minimum thickness on the structural high of Circeo Promontory, sharply increasing to the north and to the south. To the south the sequences thicken towards the Terracina basin and the Fondi offshore. More southwards (south of the Garigliano basin) the post-MIS 5 sequence thickens enormously, probably influenced by the great volcanoclastic input due to the explosive eruptions of the Campi Flegrei Volcano (main activity 50-10 kyr).

The highlighted stratigraphy of Southern Latium shelf and Northern Campania shelf therefore it is a very good example of how the building of the 4th-order depositional sequences depends and may highlight the interplay between sea-level oscillations, regional subsidence and sediment supply.

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Upper Pleistocene contourite deposits off the Capo Vaticano margin (southern Tyrrhenian Sea, Italy): interplay between down-slope and along-slope sedimentary processes

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Keywords: Upper Pleistocene, contourite deposits, southern Tyrrhenian Sea, Italy.

Both down-slope gravity currents and along-slope bottom currents are common phenomena occurring along most continental margins (Mulder et al., 2008), however mixed depositional systems related to these processes are yet poorly documented (e.g., Hernández-Molina et al., 2009). In semi-enclosed and tectonically active basins down-slope phenomena are more frequent; however, small contourite systems can be locally recognized. In this study, based on very high-resolution single-channel seismic profiles and multibeam bathymetric data, we investigate the upper slope and shelf deposits along the southern sector of the Capo Vaticano continental margin (Calabro-Tyrrhenian margin) where, between ~500 and 90m water depth, the stratigraphic record is characterized by hemipelagic, contourite, turbidite and mass wasting deposits formed in different upper Pleistocene eustatic cycles.

The most recent part of the stratigraphic record has been analyzed by Martorelli et al. (2016), showing that during the last glacio-eustatic cycle, along-slope processes formed elongated drifts located on the upper continental slope and outer shelf, between -90 and -300 m. Here, contourite deposits and associated erosive elements indicate the presence of a northwestward geostrophic flow that can be related to the modified-LIW issued by the Messina Strait and it is likely that the activity of bottom-currents was intensified around the LGM period and during the successive sea-level rise. Down-slope processes formed mass-transport deposits and turbidite systems with erosive channels, locally indenting the present-day shelf. Moreover, slide events affected the upper 10–20 m of the stratigraphic record, dismantling considerable volume of contourite sediment. The most striking mass wasting feature is the Capo Vaticano slide complex (the CVSC), which displays a large spatial coverage and is composed by several intersecting slide scars and overlapping deposits. The presence of high-amplitude reflectors within contourite deposits (i.e., potential weak layers), along with high post-glacial sedimentation rates estimated for contourite deposits and steep seaward flank of the drifts can act as a relevant predisposing/triggering factor for medium-large scale slope instability.

In this study we highlight how a complex spatial and temporal interplay of along- and across slope processes can occur over a narrow area in a relatively short time-span (e.g., the post-glacial period), and that a similar interplay can be observed within pre LGM deposits. As a whole seismic data indicate that both these processes were relevant in shaping the study margin throughout the upper Pleistocene.

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Martorelli E., Bosman A., Casalbore D. & Falcini F. 2016. Interaction of down-slope and along-slope processes off Capo Vaticano (southern Tyrrhenian Sea, Italy), with particular reference to contourite-related landslides, Marine Geology http://dx.doi.org/10.1016/j.margeo.2016.01.005.

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The Taranto Landslide (northeastern Ionian Sea): stratigraphic framework and geological model

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Keywords: Taranto Landslide, Stratigraphic framework, Geological model, Geohazard.

This study is focused on the Taranto landslide, an impressive landslide located in the north-eastern sector of the Ionian Sea, offshore of Taranto coast. The analyzed data encloses multibeam echo sounder and high resolution seismic profiles. This landslide is classified as a *slide*, the headwall is at a depth of 370 m, the toe is at a depth of 900 m, for a total length of about 9 km. Basing on morphological features the estimated volume is about 0.30 Km^3.The sediments involved have been referred Early and Middle Pleistocene following the interpretation of seismic profiles. In addition, parameters defining the slide kinematics have been calculated, by means of empirical formulas. They are: Landslide duration, Mean Velocity and the Peak of velocity. The resulting values highlighted that the slide is extremely rapid, and the sediment accumulation underwent to process of rapid emplacement. Also the landslide tsunamigenic potential has been assessed by empirical calculation assuming a mass translation of the involved sediments. The magnitude of resulting value has even highlighted that this kind of movement is potentially dangerous for coastal infrastructures. One possible factor triggering the Taranto Landslide is the presence of a significant tectonic lineament, SW – NE trending, produced by the activation of a normal fault. Faults with same trending and in activity in a range between 3 and 0.7 Ma BP, have been identified on land in Puglia region (Ciaranfi et al., 1983). In the same time span in Southern Apennines several stages of tectonic activity have been identified, the last of which was dated to about 0.7 Ma BP (Brancaccio & Cinque, 1988; Patacca & Scandone 2001, 2007). Therefore the activation of the fault indentified on seabed could has been a possible trigger for the detachment of the Taranto Landslide. New seismic profiles acquired in May 2016 allow to reconstruct a detailed stratigraphic framework and a well defined the geological model for this huge slide.

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Post-orogenic evolution of the central Tyrrhenian margin: insights from high penetration and high resolution seismic reflection profiles

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Keywords: Pockmarks, magmatic intrusions, shear zones.

Reconstruction of buried geological structures is a strategic tool for the evaluation of subsurface resources. Three different seismic grids, located in the Gaeta Gulf, enabled structural and stratigraphical observations on the post-orogenic evolution of the central Tyrrhenian margin. High penetration and high resolution seismic profiles provided different details of investigations, enabling us to better comprehend the structural pattern and the geometrical relationships between major tectonic discontinuities, merging in the study area in a complex accommodation zone and Late Quaternary magmatic intrusions and degassing features. The individuation of structures and the distribution of deformational patterns on the interpreted grids, enabled the building of a kinematic model and the reconstruction of structural synthetic maps, reflecting the timing of tectonic events affecting the margin form Miocene to Pleistocene times. Data from high penetration seismic lines have been used to reconstruct the geometry and structural setting of the offshore sectors of the Latium and Campanian Tyrrhenian margin. The 3D modelling of the base of the Plio-Pleistocene seismic units revealed the occurrence of NNE-SSW and WNW-ESE right and left-lateral shear zones. Releasing bends, structural inversion and normal listric faults were displayed by seismic profiles enabling the reconstruction of the main principal displacement zones active in Plio-Pleistocene times. Vertically stacked depressions, conduits, sediment mobilization processes and intruded acoustic transparent bodies have been observed on Chirp high resolution profiles. Identified and mapped pockmarks, displayed an WNW-ESE trending direction. The superficial venting structures are located above a main acoustic turbidity zone detected by the observation of more deep Sparker profiles. Vertical funnel shaped and downward tapering anomalies, interpreted as conduits and pipes, located immediately below the main detected pockmark field, come from a deeper fluid/gas pocket and have been individuated in the southeastern area of the interpreted grid. The main trending direction of this front is similar to the one observed for a detected volcanic edifice. This observation could suggest that magmatic intrusions produced the expulsion of great volumes of pore-waters, creating this laterally extensive seismically detected fluid/gas pocket that followed an E-W trend, correlatable with the main direction of normal to oblique faults active during Quaternary times.

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Gravitational processes of Last Glacial Maximun palaeo shoreline in the Sardinian Continental Margin

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Keywords: submarine landslide, debris avalanche, hypercinal flow, canyon dynamics, upper slope geomorphology.

The structure of the South Sardinian Margin is characterized by two deformational regimes. The oldest corresponds to a compressive phase of crustal thickening during the Oligocene Miocene, contemporary to the rotation of the Sardo-Corso block and the opening of the Algero-Provencal basin, and the last is related to Plio-Quaternary events.

Based on multibeam data collected during MAGIC (Marine Geohazard along Italian Coasts) surveys, integrating with seismic data acquired during previous research projects (Progetti Finalizzati CNR "Margini continentali"), several gravitational instability events, movements related to the Last Glacial Maximum (LGM) palaeo sealevels evolution in South Sardinia Margin have been detected. (Lecca et al., 1998)

Geomorphological evidences of LGM sea levels, have been found off San Pietro Island (south-western Sardinia), Palaeo-cliffs up to 50 meters high, carved in the volcanic substratum and tied up to tectonic lineations oriented NNW-SSW and NE-SW, with rotational landslides and some big falls blocks. 12 nm off Punta Geniò at the base of the palaeo-cliffs, it was detected a paleo-lagoon (-129 -121 m BSL) containing a litoral and marine thanatocoenosis showing a radiocarbon age of 21.9 ka cal BC (Orrù et al., 2016).

In the Gulf of Cagliari Shelf break, gravitational instability processes are represented by two major landslides located 10 Nm off the coast of Cagliari, the landslide body is affected by processes of base scouring due to the migration of lateral erosion of the Pula Canyon. 10 nautical miles off Punta Zavorra, on an isolated strip of continental shelf (-110 -125 m BSL), were recognized block landslides evolved along the main tectonic features (NW-SE) that give rise to a debris avalanche deposit. Gravitational instability occurs at the upper area of the eastern side of Cagliari Gulf, in the Foxi canyon' heads is located, at a depth of – 125 m, a gravitational instability area, with creep movements and "crescent-shaped bedforms". Here Hyperpycnal flows accumulating on the unstable continental shelf edge, can overload the shelf break, increasing the risk of gravitational slump. and the triggering of submarine mass movements. There is thus a convergence of indicators in different morpho-structural contexts that relates the first phases of sea level rise from LGM with gravitational processes evolution.

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Active deformation in Naples Bay evidenced by integrated high-resolution marine geophysic surveys and InSAR data processing

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Keywords: geophysic survey, InSAR, Naples.

Despite the growing interest for both the exploration of marine sectors and the structural mapping of fractures potentially related to the emplacement of volcanism offshore the Campanian Plain and Napoli Bay, a deep knowledge of the marine active deformation is still lacking, even if it is a fundamental task for the hazard evaluation.

The Bay of Naples is a Middle Pleistocene half-graben filled by mixed sisliciclastic-volcanoclastic depositional sequences arranged in aggradational–progradational stacking patterns. Several major faults connecting marine morpho-structural features with the main volcanic complexes (Somma-Vesuvius, Campi Flegrei, and Ischia) were mapped in the last 20 years. Deformations related to both volcano-tectonic and regional-tectonic stress fields were recorded from historical, geomorphological, geophysical and archaeological sources.

In order to fill this gap, an integrated marine geophysics and satellite remote sensing study of Naples Bay (Italy) has been carried out and it has allowed to evaluate the presence, magnitude, areal extent and activity of a structural bend affecting the post Last Glacial Maximum (LGM) sedimentary sequences, named NADEL - Naples Active Deformation Line.

The marine geophysical study was based on sparker high-resolution mono-channel profiles and multibeam swath bathymetric data, that were acquired along the continental shelf and the upper slope of the Naples Bay during the SAFE_2014 research cruise, carried out on board of the Urania R/V of CNR on August 2014.

The marine geophysical study was integrated with the analysis of the ground deformation field of the emerged sectors of the study area (Sorrento Peninsula and Campi Flegrei), derived by Synthetic Aperture Radar interferometry (InSAR) data, referred to the 1993-2000 and 2003-2008 time periods. The InSAR data obtained from the ERS and RADARSAT satellite images were processed with the method of Permanent Scatterers (PS).

Marine geophysical data provide evidence of morphological and stratigraphic features related to the NADEL element extending for about 18 km along a N130E strike. The NADEL deformation bend divides a NE offshore area, characterized by a flat morphology (slope< 1°, on average) from a SW sector, where the slope at >180 m below the sea level is, on average, 1.5°). In the area located SW of NADEL, the slopes are morphologically characterized by the presence of the uppermost active branches of the Magnaghi canyon, which are bounded upward by the presence of the NADEL pattern. Thus, we suppose that the emplacement of the Magnaghi branches and NADEL are linked. InSAR data show that a similar deformation pattern can be detected also inland, along the carbonate units cropping out in Sorrento peninsula, in correspondence to the distal sectors located NW and SE from the NADEL edges. The NADEL segments also affect the distal SW sector of the Campi Flegrei active caldera, thus resulting extended in length for more than 40 km.

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Mineralogical and geochemical characterization of marine sediments from the mud diapir province of the Paola Basin (Southern Tyrrhenian Sea)

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Keywords: Geochemistry, Mineralog, Southern Tyrrhenian Sea, pockmarcks.

The Paola Ridge is a NNW–SSE 60-km long anticline that confines with the Paola Basin westward (NW Calabrian margin) and is located in the SE portion of the Tyrrhenian Sea. The Paola Ridge had recently been re-interpreted as due to a mobile mud belt (including three diapirs: D1, D2 and D3 and two mud volcanoes: MMV and RMV), connected with a set of extensional NW-SE to NNW-SSE trending faults (Gamberi & Rovere, 2010). The MVP11and MarBeep oceanographic cruises were carried in 2011 and 2014 on board the R/V CNR Urania. During these cruises, other than multi-beam, bathymetric data and CHIRP profiles, gravity coring and box coring samples were acquired to define the sedimentological, petrographical, mineralogical and geochemical features of the marine sediments. The studied samples were obtained from cores and box cores, collected along the selected structures of the Paola Ridge and were classified, as follows: limestone crusts, carbonates of tubular form, iron oxy-hydroxide crusts, pyrite and sulfur crusts and cohesive mud. Each sample was analyzed by means of optical petrography, XRD, SEM-EDS, XRF, ICP-AES and ICP-MS. Selected samples were chosen for carbon, oxygen and sulfur isotopic analyses. The petrographical, mineralogical, chemical and isotopic data, presented in this work, allowed to define the depths of the biogeochemical zones and the geochemical processes affecting the depositional environment into which the marine sediments were deposited (Rovere et al., 2015). Authigenic calcite and aragonite, associated with chemosymbiotic bivalve assemblages, were discovered on pockmarks along faults cutting the mud diapirs. Stable isotopes (C and O) on these carbonates resulted to be depleted in $\delta^{13}C$ and slightly enriched in $\delta^{18}O$, suggesting that authigenic carbonates were likely deriving from bacterial oxidation of methane.

Several sites were sampled from and inside the mud volcanoes. Iron oxy-hydroxide crusts, mainly consisting of goethite, were found on the seafloor. Pyrite and sulfur crusts showed a mineralogical composition consisting of pyrite and/or sphalerite, quartz and few feldspars. Tubular authigenic carbonates contained siderite, quartz and few phyllosilicates. Stable isotopes (C and O) of siderite showed enrichment in both carbon and oxygen.

Cohesive mud samples were dominated by quartz, halite, feldspars, muscovite and clay minerals (illite, vermiculite, chlorite, kaolinite) while in some samples the presence of calcite or dolomite, siderite, hematite and pyrite was recognized.

Gamberi F. & Rovere M. 2010. Mud diapirs, mud volcanose and fluid flow in the rear of the Calabria Arc orogenic wedge (southeaster Tyrrhenian Sea). Basin Res., 22, 452-464.

Rovere M., Rashed H., Pecchioni E., Mercorella A., Ceregato A., Leidi E., Gamberi F. & Vaselli O. 2015. Habitat mapping of cold seeps associated with authigenic mineralization (Paola Ridge, southern Tyrrhenian): combining seafloor backscatter with biogeochemistry signals. Ital. J. Geosci., 134, 23-31.

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Normal faults control fluid flow structures at the rear of the Calabrian Arc (Paola Ridge, southeastern Tyrrhenian Sea)

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Keywords: pockmark, Tyrrhenian Sea, Messinian evaporites, gas venting,multichannel seismic data.

The Paola Ridge is a NNW-SSE 60-km-elongated anticline that confines the Paola Basin westward on the lower continental slope of the NW Calabrian margin (southeastern Tyrrhenian Sea), where pockmarks and mud flow structures were initially discovered at 500-1000 m water depth on full-ocean depth multibeam and backscatter data (Gamberi and Rovere, 2010). Higher resolution geophysical data and seafloor samples were acquired in 2011 (Rovere et al., 2014). The acoustic data in the water column lead to the discovery of active gas venting at the seafloor in the structures characterized in the sub-seafloor by the precipitation of sulphide and siderite burrows, the latter showing enrichment in $d^{13}C$ and $d^{18}O$, compatible with the methanogenic zone (Rovere et al., 2015). In the structures characterized by fields of pockmarks on top of them (mud diapirs), authigenic calcite and aragonite, associated with chemosymbiotic shelly macro fauna (*Lucinoma borealis* and *Acharax* sp.), have formed near the seabed in the last 40,000 years. The carbonates have the isotopic signature indicating formation during sulphate-dependent microbially-mediated anaerobic oxidation of methane.

The seismic data available at the time preliminary showed that NW-SE and NNW-SSE-oriented normal faults were the most probable mechanism for the emplacement of some of the structures. These faults appear to be the marine prolongation of the NW-SE oriented fault zones that dissect the Calabrian Arc. With the aim of better understanding the structural setting of the area, in June 2014 a seismic survey was undertaken and 322 km of multichannel profiles were acquired. The seismic source was a single 60 in^3 mini GI-gun set in Harmonic Mode (30 Generator + 30 Injector) with a shot interval of 9.375 m at 2000 psi and the receivers were made of a 300-m-long, 96 channels digital streamer with a trace distance of 3.125 m.

Acoustic detection of the water column, using both Kongsberg EM710 and EM302 multibeam systems, fully imaged dozens of distinct gas flares, which correspond to seismic zones of free gas accumulation in the sub-surface.

The seismic data unveiled that the mud diapirs lie directly on top of diapirism of the Messinian evaporites and develop along deep-rooted normal faults, that sometimes breach through the M reflector itself. Faults most probably were no longer active at the base of the Plio-Quaternary reflector.

Gamberi F. & Rovere M. 2010. Mud diapirs, mud volcanoes and fluid flow in the rear of the Calabrian Arc Orogenic Wedge (southeastern Tyrrhenian sea). Basin Res., 22, 452-464.

Rovere M., Gamberi F., Mercorella A., Rashed H., Gallerani A., Leidi E., Marani M., Funari V. & Pini G.A. 2014. Venting and seepage systems associated with mud volcanoes and mud diapirs in the southern Tyrrhenian Sea. Mar. Geol., 347, 153-171.

Rovere M., Rashed H., Pecchioni E., Mercorella A., Ceregato A., Leidi E., Gamberi F. & Vaselli O. 2014. Habitat mapping of cold seeps associated with authigenic mineralization (Paola Ridge, southern Tyrrhenian Sea): combining seafloor backscatter with biogeochemistry signals. Ital. J. Geosci., 134, 23-31.

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Geomorphic and tectonic control on the distribution of coral-topped mounds in the northern Ionian margin (eastern Mediterranean Sea)

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Keywords: Submarine slide topography, mass-transport deposits, cold-water corals.

Over the past 10 years a large dataset of bathymetric, seismic, sedimentological and video data, that covers more than 2000 km^2, was acquired along the Apulian ridge (northern Ionian margin) between 80 and 1400 m of water depth (Corselli, 2010 and references therein). Surficial or sub-surficial occurrence of different and coalescent late Pleistocene Mass-Transport Deposits (MTDs) was documented by seismic facies analysis, downslope of a series of arcuate-shaped scars that mark the upper slope at the transition zone of the continental shelf. Where exposed or partially exposed, the MTDs exhibit very complex morphological structures, including extensional and compressional ridges and numerous separated blocks of sediment up to a few hundreds of meters in diameter and between 10 to 20 m in height. A total of ten sediment blocks were sampled and/or explored with ROV dive and underwater cameras. The obtained dataset indicated dense occurrences of living Cold-Water Coral habitats (including the L. pertusa and M. oculata coral frameworks) on their tops and flanks, thriving between 500 and 900 m of water depth and forming thus coral-topped mounds. Over a broader scale, coral topped mounds are particularly aggregated at the top of the regional blocks that dissect the Apulian ridge through a series of NNW-SSE oriented normal faults. Such configurations have been interpreted to be a result of a recent margin evolution that underwent regional uplift during the Late-Middle Pleistocene. Uplift reduced the accommodation space and created a physiographic context where large areas became swept due to local bottom-currents, especially on the tops of large-scale, up-thrown, faulted regional blocks due to their elevated position. Such areas include most of the portions of the MTDs and associated coral-topped mounds mapped within the surveyed area. In addition, mutual cross-cutting relationships have been recognized between fault scarps and MTDs, indicating that the NNW-SSW normal fault network in the Apulian ridge can be considered active (or at least active till the Holocene-Pleistocene boundary). Our work sought to document how the peculiar biotopes that make the Ionian Margin a relevant hotspot of biodiversity within the eastern Mediterranean Basin result from specific environmental conditions strictly controlled by the interplay between landslide seafloor morphologies (generated by past multiple failure events), tectonic activity, and local hydrographic patterns.

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Fluid escape structures revealing volcanic and tectonic activity in the Graham Bank (Sicily Channel)

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Keywords: Graham Bank, Fluid escape structures, Pockmarks, Mounds, Plumes, Tectonics, Volcanic Context.

The Graham Bank (NW Sicily Channel, Central Mediterranean) is characterised by a complex seafloor morphology, where morphostructural highs, submarine plain, escarpments, and negative and positive relieves indicate a complex structural setting and the occurrence of seepage fluids.

New high-resolution acoustic data (multibeam, Chirp profiles) and multi-channel profiles, allowed us to differentiate two main morphological sectors, and to identify several pockmarks and mounds linked to fluid escape phenomena.

The eastern sector, corresponding to the volcanic edifices of the Graham Bank, is characterised by volcanic context with rough morphology, several mounds, focused seepage plumes and magmatic acoustic substrate, all related to the activity forming both the Graham Bank and the new volcanic cones here identified.

The western sector displays a generally flat morphology dominated by Late Pleistocene-Holocene outer shelf deposits, where mounds and pockmarks with sub-circular and ellipsoidal shapes, V- to U-shaped in cross-section, are the prevailing features indicating the migration of fluids to the seafloor.

These two areas are separated by a vertical deep fault forming a deeply incised channel with NW-SE direction. The latter is bordered by steep walls forming fault escarpments, which shed the eroded materials to the adjacent lower slope and deep-water zones.

The overall morphostructural setting suggests a tectonic control in the morphological conformation of the seabed and in the distribution of both pockmarks and mounds. The aligned mounds have both NW-SE and NNW-SSE orientation, sometimes extending several hundred metres and forming hummocky surfaces. The aligned pockmarks are strictly comparable to the orientation of the faults related to the most recent tectonic activity.

The good correlation between fluid escape structures and the main fault systems involving the kilometric sedimentary cover suggests that the degassing of fluids is rooted in depth revealing that extensional tectonics acts with very deep sub-vertical recent faults developing along and reactivating the Cenozoic (both Plio-Quaternary and Messinian) and Mesozoic tectonic systems.

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Volcano- and neoectonic-related slope failures in the north-western Sicily Channel (central Mediterranean Sea): Implications for understanding and assessing geohazard risk

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Keywords: Seafloor mapping, Geo-hazard, Tsunami.

The southern Sicily coasts represent an important contribution to Italian tourism and marine geological processes in the Sicily Channel could pose a significant risk to neighbouring populations and goods.

In this work, we are presenting the first results of the data collection that allowed us to identify and map several geological elements that can be used to assess submarine geohazards in the Sicily Channel. By using multibeam data and high-resolution seismic reflection profiles acquired during the ACUSCAL 2015 Cruise, we defined the characteristics of the morphostructural highs, and the morphology of slope failures and the stratigraphy of the mass transport deposits (MTD).

In particular, we studied in detail the Graham Bank, which is located in a shallow sector of the north-western Sicily Channel at a distance of 45 km from the Sicilian coastline, where seven seamounts (M1-M7) have been identified and studied in detail within a small area, between 10 and 350 m deep. Their morphometric parameters allowed classification to be implemented on a shape basis. The volcanoes are 115-180 m high and 500-1500 m wide. M2 and M3 (3.5 km X 2.8 km) form the Graham Bank. Most of them show strongly inclined flanks with an average slope of 30°. Most of these seamounts are aligned along two trends (NW-SE and N-S), parallel to the main tectonic structures of the Sicily Channel. The identified structures show physical characteristics, which are very similar to several submarine volcanoes described elsewhere on the seafloor, allowing to conclude that they are volcanic seamounts. In this regard, it is important to highlight that the Graham Bank was affected in the last 100 years, by many eruptions (Colantoni et al. 1975).

Furthermore, we distinguished slope failures relating to different mechanisms. In the western flanks of the M2 and M3, volcanic activity and concurrent up-slope triggered mass failures. In the eastern flank M2 gravitational collapse of volcanic edifices is mainly linked to neotectonic activity and volcanism. In the central part of the study area, a MTD is linked to neotectonic activity and to the rise up of volcanic rocks. These MTDs were mapped and described as potential tsunamigenic elements and their volumes were estimated. This work allowed us to understand geological features and processes in a tectonic-volcanic environment, which may represent a threat for coastal areas of the southern Sicily.

Colantoni P. 1975. Note di Geologia Marina sul Canale di Sicilia. Giornale di Geologia (2), 40, 1, 181-207.

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Seabed morphology, sub-seabed structure, and deformation mechanism of an active degassing field (Gulf of Naples, Italy)

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Keywords: seabed deformation, fluid discharge, non-volcanic unrest.

The processes associated with shallow water hydrothermal fluid discharge on continental shelves are far to be fully understood. We report geomorphological, morphometric, geophysical, and geochemical evidences of a 5.5 x 5.3 km seabed uplift area located 5 km south of the Napoli harbor (Italy). This area is between 100 and 170 m b.s.l., it is 15-20 m higher than the surrounding seafloor, and it is characterized by a hummocky morphology due to 280 subcircular to elliptical mounds, about 660 cones, and 30 pockmarks. The mounds and pockmarks alignments follow the strike of the main tectonic structures affecting the Gulf of Naples. The seafloor swelling and breaching require relatively low pressures(about 2-3MPa), and the sub-seabed structures, which consists of diapiric-like 'pagodas' affecting the present-day seabed, record the active upraise, pressurization, and release of gas. The gas composition of the sampled submarine emissions is consistent with that of the hydrothermal systems of Ischia, Campi Flegrei and Somma-Vesuvius active volcanoes,and CO_2 has a magmatic/thermometamorphi corigin. The $^3He/^4He$ values are slightly lower than in the Somma-Vesuvius and Campi Flegrei volcanoes indicating the contamination of fluids originated from the same magmatic source by crustal-derived radiogenic ^4He. All these evidences concur to hypothesize an extended magmatic reservoir beneath Naples and its offshore. Seabed doming, faulting, and hydrothermal discharge are manifestations of non-volcanic unrests potentially preluding submarine eruptions and/or hydrothermal explosions. A mechanical model of seabed deformation and uplift is proposed along with an estimate of the pressures required for swelling and seafloor breaching. The growth mechanism of the investigated structure is also proposed. We conclude that seabed deformations and hydrothermal discharge must be included in the coastal hazard studies.

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Seafloor response to sediment supply from volcanic activity in the Neapolitan coastal area, Eastern Tyrrhenian Sea

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Keywords: Napoli Bay, geohazard, volcaniclastic deposits.

Sudden emplacement of large amount of pyroclastic material from explosive eruptions represents a significant interference with the geomorphic system, both for inland and submerged areas, inducing sediment overburden and consequent return to the equilibrium profile by means of land degradation and erosional processes. Volcanoclastic resedimentation and generation of mass flows and floods are common phenomena affecting wide areas near the volcanic vents, occurring both soon after volcanic eruptions and during inter-eruption periods. In volcanic coastal areas volcanic debris can enter the sea in the form of mass flow or as the underwater continuation of subaerial surges. Rapid accumulation at sea of tephra deposits from explosive eruptions can led to seafloor failure or act as weak layers for successive gravity deformations. Yet, part of volcaniclastic material can be stored in the catchments and be available for erosion a long time after an eruption.

The study area includes among the most active volcanoes, namely Phlegrean Fields and Somma-Vesuvius, which significantly influenced the marine depositional system and the drainage network since the Pleistocene. The volcanic activity started about 300-400 ka in the Vesuvian area and about 150 ka at Ischia Island. Oldest volcanic products in the Campi Flegrei area date back to > 60 ka with more than 200 km^3 of trakyte and phonolite erupted 39 ka during the Campanian Ignibrite super eruption and about 40 km^3 of erupted magma about 15 ka during the Yellow tuff trachytic phreatoplinian eruption. In the Pozzuoli area major periods of volcanic activity occurred from 10.0 to 8.0 ka B.P and 4.5 to 3.7 ka B.P with two main plinian events: the Aganano Pomici Principali and the Agnano Monte Spina eruption. Consequently, numerous monogenic volcanoes formed close to the shoreline and many of them are presently submerged at different depth in the Flegrean coastal area.

The aim of this paper is to discuss the influence of volcanic activity on the Neapolitan coastal depositional system. Seafloor geological features were used as indicators for volcanic processes often only partly detectable along subaerial slopes. High-resolution geophysical surveys were carried out in shallow water at mouth of bedrock streams and small rivers that were affected by pyroclastic deposition and off coastal volcanoes. A set of geophysical data imaging deeper seafloor areas has been used to illustrate mass flows occurring on the shelf break and continental slope. Data from geologic investigations in the contiguous sub-aerial coastal slopes have been also taken into account.

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A geo-statistical predictive approach to the Habitat mapping of Vulnerable Marine Ecosystems along the northern Sicily inner continental shelf (southern Mediterranean)

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Keywords: MaxEnt, geostatistical prediction, Habitat mapping, Vulnerable Marine Ecosystem.

The main aim of this work is to statistically predict the distribution of Vulnerable Marine Ecosystems (VMEs) along the continental shelf regions of the northern Sicilian margin (southern Mediterranean).

The considered habitats, already mapped in the area on a qualitative base, are the *Posidonia oceanica* and *Cymodocea nodosa* seagrasses and the Coralligenous biocenosis. *Posidonia oceanica* and Coralligenous are considered as VMEs owing to their value as environmental indicators and biodiversity hotspots in coastal marine areas. For this reason, several actions were aimed in recent years to their complete characterization and mapping.

The study area is located in the continental shelf of the northern Sicily margin, between the Cape San Vito (Gulf of Castellammare) and Cape Zafferano (Gulf of Palermo).

Different physical characteristics of the seafloor were extracted from a database acquired in recent years in the frame of official national cartography (CARG) and hazard assessment (MAGIC) Italian Projects, including geological and geophysical data (seabed sampling, ROV footage, multibeam bathymetry, backscatter maps, high resolution seismic reflection records).

The ultimate goal is to apply a statistical methodology allowing to predict the distribution of marine habitats from a "presence only" sampling dataset. This target was pursued by using a multidisciplinary approach, including abiotic (i.e. depth, morphological and hydrodynamic features, type of seabed) and biotic components (benthic communities) that define and characterize the mapped habitats.

Predictive maps are based on the Maximum Entropy model (MaxEnt), a statistical method based on punctual occurrence of specimen (presence-only). The punctual occurrence of the three habitats was already known, whilst we considered the bathymetry, seabed steepness, aspect, fluid escape, erosional areas and sediment type as physical features for the model.

The analysis was also aimed to test the performance of models obtained by choosing the training samples with different criteria. Therefore, different outputs (42 in total) have been produced by selecting samples on the basis of the area (regional analysis), the type of coasts (morphological) or randomly (random). Moreover, the models were built up both with only training samples either with training and test samples to obtain more constrained distribution patterns.

Almost all the created predictive models produced good performances, with statistical parameters (gain, AUC standard deviation) very positive on average. The models derived from the regional analysis resulted to be more performing than the others, with the random-derived being the worst. The response curves pointed out that bathymetry and sediment types are the most important physical features influencing the distribution of the mapped VMEs, whereas aspect and slope are not-independent variables. These outputs also provided important information and constraints on the favorable environmental conditions for the three habitats.

Results from this preliminary statistical modeling appears potentially useful in the evaluation of important environmental parameters, allowing to draw the broad distribution of marine habitats in areas where only presence data are available, and can represent a contribution in the design and monitoring of marine protected areas.

SESSION S23

Tephras and cryptotephras in Quaternary sciences

CONVENERS AND CHAIRPERSONS

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MeSCo database as a tool for integrated stratigraphy studies in the Mediterranean Basin

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Keywords: Marine sediment cores, radiocarbon dating, tephra, oxygen isotope, database, Mediterranean Sea.

Despite the conflicting opinions regarding the reliability of biotic and abiotic "proxies" used for the reconstruction of past climates, the analysis of temporal series remains the only valid tool to study the Earth's dynamic processes in different conditions from those of the current period. In this framework, MeSCo (Mediterranean Sea Cores) database was implemented to host the entities which record quantitative data on tephra layers, $\delta^{18}O$ and AMS ^{14}C.

Published data concerning paleoclimatic proxies in the Mediterranean Basin come out from only 400 of 6000 cores recovered in the area and they show an irregular geographical distribution pinpointing few zones with high density and others with total lack of data. Moreover, the data availability decreases when a constrained time interval is investigated or more than one proxy is required. Despite these shortcomings, we present three successful applications of MeSCo to the Younger Dryas (YD) paleoclimatic event at Mediterranean scale. Taking into account the number of AMS^{14}C ages available in literature (572) from a total of 104 cores, it results that the YD geochronological interval is documented by few samples useful as tie points to construct age-models and to define the sedimentation rates for the different sectors of Mediterranean basin. Furthermore, the depth position of the AMS^{14}C dating samples evidences a high sedimentation rate in the Alboran and Adriatic basins followed by the Sicily Channel whereas low values characterize the other zones of Western Mediterranean Sea.

The geographical distribution of $\delta^{18}O$ samples, measured on *Globigerina bulloides* and *Globigerinoides ruber alba* variety, allowed the zoning of the Western and the Eastern Mediterranean Sea, respectively. The *G. bulloides* $\delta^{18}O$ values, ranging from 3.7 to 1.7‰, are high in the Adriatic and central Tyrrhenian basins, the former being one of the coldest areas of Mediterranean. Both areas are characterized by high density of water masses that sink creating the Eastern Mediterranean Deep Water (EMDW) and the Tyrrhenian Deep Water (TDW), respectively. The *G. ruber* $\delta^{18}O$ values, ranging from 2.65 to 0.12‰, in the Sicily channel and Aegean Sea are higher than elsewhere in the Mediterranean. This biotic signal could be linked to the passage of the Modified Atlantic Water (MAW) through the Sicily channel and to the lower temperature and salinity concentration of Aegean Sea waters than those of the neighboring zones.

A further powerful use of MeSCo for the correlation of marine archives is the possibility to easily identify the occurrence of tephra beds within all the cores stored depending on whether the user asks for a specific volcanic source, composition, age or distal equivalent. Moreover, queries can be run to rapidly integrate tephra data with those deriving from other proxies (eg. AMS^{14}C). In this regard, MeSCo was successfully applied to identify the occurrences of two possible tephra markers for the YD time interval: the Agnano Pomici Principali tephra, mainly found in the Adriatic Sea cores, and the Soccavo1 tephra, spread in the Tyrrhenian Sea.

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Trace element compositions of the tephra layers recorded in the Lake Suigetsu (Honshu Island, Japan) sedimentary record: An insight into compositional variation along the arc and the tempo of volcanism

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Keywords: Tephrochronology, Japan, Lake Suigetsu, Trace elements.

The sediments of Lake Suigetsu (Honshu Island), central Japan, extend approximately the last 150,000 years and provide a detailed record of explosive volcanism for Japan and South Korea (Smith et al., 2013). The upper portion of the Lake Suigetsu record (sediments younger than 50 ka) are precisely dated using a combination of counting the annual laminations in the sediments (varves) and radiocarbon dating (Bronk Ramsey et al., 2012). This archive offers enormous potential to unravel the tempo of explosive volcanism of numerous volcanic centers and to assess their geochemical evolution. Thirty visible tephra layers were reported from the Lake Suigetsu SG-06 sediment core, with only some of these layers being linked to individual volcanic sources or eruptions on the basis of their major element volcanic glass compositions (Smith et al., 2013).

Presented here is grain-specific trace element volcanic glass data for the SG-06 tephra layers and proximal tephra sequences of probable volcanic sources. Proximal deposits sampled include those of the large caldera volcanoes along the Ryushu-Kyushu arc (Aso, Aira, Ata & Kikai) and the stratovolcanoes of the southwestern Japan arc (Daisen & Sambe). Proximal glasses reveal important compositional variations between the different volcanic centers, and along the arc. This glass dataset has allowed us to precisely test tephra correlations assosiated with of some of the largest and most widely dispersed Late Quaternary Japanese eruptions (e.g., Ata, Aso-4, K-Tz, AT, K-Ah). The new trace element data provide diagnostic geochemical 'fingerprints' for the different volcanic centers investigated. This has enabled us to confidently assign previously un-correlated SG-06 tephra layers to explosive events from Daisen and Sambe volcanoes. The Lake Suigetsu record offers particularly useful insights into the tempo of volcanism at Daisen volcano. The geochemical 'fingerprints' generated here will facilitate the use of these tephra layers as isochrons and will enable the precise synchronisation of disparate sedimentary archives within paleoclimate studies.

Bronk Ramsey C., Staff R.A., Bryant C.L., Brock F., Kitagawa H., van der Plicht J., Schlolaut G., Marshall M.H., Brauer A., Lamb. H., Payne R., Tarasov P. E., Haraguchi T., Gotanda K., Yonenobu H., Yokoyama Y., Tada R. & Nakagawa T. 2012. A Complete Terrestrial Radiocarbon Record for 11.2 to 52.8 kyr B.P. Science 338, 370–374.

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Volcanic glass geochemistry of explosive deposits in the Aeolian Islands: A proximal database for distal tephrochronology

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Keywords: Tephra, Aeolian Islands, volcanic glass chemistry, trace elements.

Volcanic ash (< 2 mm) erupted from the Aeolian Islands is reported distally as layers in sedimentary archives from across the central Mediterranean region. These layers offer important stratigraphic markers (tephrostratigraphy) suitable for synchronising palaeoclimate archives, and where they can be correlated to dated eruptions they represent key chronological markers (Tephrochronology). The promise of distal tephra layers for both dating and synchronising sedimentary archives relies heavily upon the detailed characterisation of volcanic glasses from proximal eruptive sequences. In this contribution we present the volcanic glass geochemistry of tephra deposits from explosive eruptions on the islands of Vulcano, Lipari, Salina and Stromboli, spanning approximately the last 50 ka following grain-specific electron microprobe analysis (EMPA) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). This comprehensive dataset of volcanic glass compositions (>1000 analyses) provides a basis for proximal-distal and distal-distal tephra correlations.

Tephra deposits from the different Aeolian Islands are geochemically diverse; with some eruptions showing stratigraphic geochemical heterogeneity. Major element glass analyses reveal that Vulcano (0-21ka) and Stromboli (5-13ka) have erupted potassic (shoshonitic and K-series) tephra with broadly overlapping compositions, but crucially their eruptive products can be distinguished using either TiO_2 contents or their HFSE/Th ratios. Whilst individual volcanic sources often produce successive tephra deposits with near identical major and minor element compositions through time (i.e., Lipari, Vulcano), trace element glass data can help to decipher the different eruptions. Changes in LREE and Th concentrations of volcanic glasses from eruptions spanning the last ~ 50 ka greatly enhance the potential to discriminate successive eruptive units on Lipari. This new proximal glass chemistry database has been used to verify new and existing distal occurrences of Aeolian Island derived tephra, enabling the reassessments of past ash dispersals. Finally, proximal and distal data have been used to establish an integrated proximal-distal eruptive event stratigraphy for the Aeolian Islands.

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Towards a ~1.5 Ma-long Mediterranean tephra record: first results for the last ~190 kyr from the Fucino Basin lacustrine succession, central Italy

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Keywords: Fucino Basin tephra, major and trace elements glass composition, Sr and Nd isotope analyses, $^{40}Ar/^{39}Ar$.

Here we present the first integrated tephrochronological study (major and trace elements glass composition, Sr and Nd isotope analyses and $^{40}Ar/^{39}Ar$ dating) for the uppermost ~82 m of the ~900 m-thick Quaternary lacustrine succession of the Fucino Basin. Located in a favorable position with respect to the prevailing westerlies, and in a good range of distance from the peri-Tyrrhenian volcanic centers (100 to 150 km) to have a quite complete record of distal tephra, the Fucino Basin is the largest and probably the only one among the Central Apennine intermountain tectonic depressions that hosts a continuous lacustrine succession documenting the Plio-Quaternary sedimentary history up to the recent historical times. Major and trace element data were collected using wavelength-dispersive electron microprobe (WDS-EMPA) and Laser Ablation Inductively Couple Plasma Mass Spectrometry (LA-ICP-MS), respectively, on glass from 22 stratigraphically ordered tephra. The obtained dataset provided the geochemical fingerprinting needed for a reliable recognition of most layers, allowing to precisely constrain the chronology of the investigated Fucino succession to the last ~190 kyrs. The Sr and Nd isotope compositions of selected layers confirm the robustness of this approach for consistently circumscribing the volcanic source of distal tephra and possibly for recognizing individual eruptive unit. To this regard, we also propose a new, more expeditious covariation diagram (CaO/FeO vs Cl) for identifying the volcanic source of trachytic to phonolitic and tephrytic to phonolitic tephra, which are the most common compositions of the volcanic rocks from Campania and Latium volcanoes. Finally, here we provide a new, analytically well-supported and more precise $^{40}Ar/^{39}Ar$ age for the widespread Y-7 tephra and the first $^{40}Ar/^{39}Ar$ age determination for a Campi Flegrei tephra dated to ~159 ka, which has the potential to become an important marker for the Mediterranean MIS 6 tephrostratigraphy. In light of these results, the Fucino sedimentary succession is likely to provide a very long, continuous tephrostratigraphic record for the Mediterranean area, extending back to ~1.5 Ma, and thus candidates to become a key node in the dense network of tephra correlations of this region.

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Preliminary mineralogical characterization of crystals from "Cava di Caolino" (Lipari Island, Sicily, Italy)

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Keywords: Lipari Island, Kaoline quarry, hydrothermal minerals.

The quarry of kaoline is located in the western sector of Lipari Island (Eolian Islands, Sicily, Italy); it extends for about 100 m along a NNW-SSE to north-south fault directions linked to the major Tindari-Letojanni structural system. The present study was devoted to characterize the mineral assemblage of the quarry consisting of a narrow open-air gallery leading to a wider, roughly circular open pit. In previous works other crystals in addition to kaolinite and gypsum have been found but they were not characterized in detail, due to the very small size (Decrée et al., 2005). The authors recognized two different kinds of kaolinite, but still it is not clear whether the second kaolinite generation grew at the expense of the first one. According with recent works, primary or secondary origins of kaolinite can be determined from the stacking sequences of crystals using high-resolution transmission electron microscopy images associated with thermogravimetric analysis (Ece et al., 2003). In this work, the mineralogical study of 20 samples collected in the kaoline quarry were performed by crossing the data obtained through different analytical techniques (*i.e.,* XRPD, TEM-EDS; SEM-EDS, μ-Raman, DTA-TG). It turns out an unexpected mineralogical richness; the detected minerals in decreasing order of amount are: kaolinite, gypsum, gibbsite, anhydrite, alunogen, jarosite, cristobalite, opal, jonesite, sophiite, metavoltine, ganophyllite, zakharovite, lunijianlaite, genthelvite, theresemanganite, eucryptite, gustavite. Crystal size ranges between 1 cm and few micron, depending on whether they are single crystals or aggregates. The thermal characteristics of gypsum produce the following thermal changes: dihydrate gypsum becomes hemihydrate gypsum at 163 °C and the hemihydrate becomes anhydrous gypsum at about 177 °C. The DSC curve shows also, a strong endothermic effect in the range from 450 to 600 °C that is typical for most kaolinites. A detailed study of such minerals improves the knowledge on geochemical evolution of the kaoline quarry in Lipari and in general on the evolution of hydrothermal environments on pyroclastic deposits.

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C^{14} dating of the Milo debris deposit at Etna volcano (Italy): new age constraints for the Valle del Bove formation

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Keywords: Etna, stratigraphy, C^{14} dating, debris flow.

The Milo debris deposit crop outs in the lower east flank of Etna volcano between about 850 m and 300 m a.s.l. covering an area of 4.3 km^2 (Branca et al., 2011). This volcanoclastic sequence is formed at the base by an almost monogenetic debris avalanche deposit up to 20 m thick, constituted mainly of mugearitic lava clasts in abundant loose matrix, that is topped by a succession of matrix-supported lahar-type debris- and mud-flow deposits up to 10 m thick. Radiocarbon age of 8.4 ka BP of the top of the sequence performed by Calvari et al. (1998) represent a minimum age for the Milo deposit whose origin is related to the lateral collapses of the eastern flank of Etna edifice that caused the initial stage of the formation of the Valle del Bove depression.

A new large excavation for the renovation of Milo village football field, located at 800 m of altitude, allowed us to measure a complete stratigraphic section of the basal sequence of this deposit consisting of an unstratified and ungraded breccia matrix-supported, about 20 m thick, made up of heterolithologic angular lava clasts with dimensions ranging from centimetric to submetric. The base of the breccia deposit is rich of well-preserved wood fragments, trunks and tree roots. C^{14} dating of two wood samples result in calibrated ages of 9270 BP and 9250 BP allowing to date, for the first time, the debris avalanche deposit generated by the opening of the Valle del Bove depression thus evidencing that its formation occurred at the beginning of the Holocene epoch.

Branca S., Coltelli M., Groppelli G. & Lentini F. 2011. Geological map of Etna volcano, 1:50,000 scale. Ital. J. Geosci., 130(3), 265-291.

Calvari S., Tanner L.W. & Groppelli G. 1998. Debris-avalanche deposits of the Milo Lahar sequence and the opening of the Valle del Bove on Etna volcano (Italy). J. Volcanol. Geotherm. Res., 87, 193-209.

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Submarine landslide events constrained by tephrochronology: the case of the southern Campania continental margin (eastern Tyrrhenian Sea)

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Keywords: continental margin, submarine landslide, geohazard, integrated stratigraphy, Late Pleistocene-Holocene.

Tephras and cryptotephras are used as stratigraphic and dating tools in high-resolution proxy records, in studies of volcanology, paleoclimate and natural hazards. The southern Campania margin, which includes the Salerno and Policastro bays, is a favourable area from this point of view because it is characterized by active tectonic lineaments and thick stratigraphic successions with large amount of pyroclastic and volcaniclastic materials erupted by the volcanic vents of the Campania Plain. The tephrostratigraphic framework built up to now for this area has proved to be a powerful tool in distinctive cases where the chronostratigraphy of geological and hazardous events, such as landslides, has to be established. We report here on tephra analysis carried out on a number of gravity cores raised from slided areas (Salerno Valley and offshore Cilento) and positioned on the base of detailed Digital Elevation Model (DEM) of the sea bed. Sampling was made at out-of-scar, in-scar and into slided deposits and the obtained results allowed us to 1) age constrain the event by correlating tephras recovered in the post-slide drape (Poseidonia slide in the Salerno Bay; Budillon et al., 2014); 2) define the role of tephra layers which could act as weak layers; 3) retrieve ancient deposits by drilling in-scar even with conventional coring systems and 4) detail stratigraphically the failed succession by comparing in-scar and out-of-scar records.

Budillon F., Cesarano M., Conforti A., Pappone G., Di Martino G. & Pelosi N. 2014. Recurrent superficial sediment failure and deep gravitational deformation in a Pleistocene slope marine succession: The Poseidonia Slide (Salerno Bay, Tyrrhenian Sea). In S. Krastel et al. (eds.), Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research 37, 273-283.

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On ash dispersal from moderately explosive volcanic eruptions: examples from Holocene and Late Pleistocene eruptions of Italian volcanoes

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Keywords: Quaternary volcanism, marine tephrostratigraphy, ash dispersal.

This research presents the results of a tephrostratigraphic analysis carried out on three gravity cores collected from the southern Tyrrhenian and the Taranto Bay (Ionian Sea). The studied marine successions, representative of shelf, slope and basin depositional settings, penetrate the last ca 13,000 years and they are generally characterised by silty and clayey deposits with rare or no disturbance. A total of thirty-eight tephras/cryptotephras were recognised along the records and their major, trace and rare element content was determined through SEM-EDS, ICP-MS and LA-ICP-MS techniques. The obtained results allowed to correlate most of tephras with the K-alkaline products of the Somma-Vesuvius, Campi Flegrei and Ischia Island whereas a lower number of analysed samples showed a composition matching with the Na-alkaline and the calcalkaline products of Mount Etna and Lipari island (Aeolian Arc), respectively. Proximal-distal and distal-distal correlations were also established. Ash dispersal maps were created for all the correlated deposits and, along with the recognition of some tephras from large eruptions that confirm or detail the previously assessed dispersal areas (Agnano Pomici Principali, Mercato, Fiumebianco-Gabellotto, Agnano Monte Spina-Astroni group, Avellino, AP3-AP4-AP5, FL, Pompeii and Monte Pilato-Rocche Rosse), we present original data concerning low to medium-energy eruptions occurred at the Neapolitan volcanoes. The recognition of deposits related to these type of events allowed to trace new dispersal maps (Pigna San Nicola, and Averno 2 from Campi Flegrei; VM1, AS2, AD 1723, AD 1730, AD 1779 and AD 1794 from Somma-Vesuvius) and to enlarge some others (Soccavo 1, Soccavo 4, Averno 1 from Campi Flegrei; Piano Liguori from Ischia Island; AP1-AP2 and AS3 from Somma-Vesuvius). According to the above conclusions, some of these moderately explosive eruptions show dispersal areas comparable to those previously assessed for subplinian events of Italian volcanoes and this aspect may play an important role for ash dispersal hazard evaluation. Moreover, the recognition of Vesuvius products both in the Tyrrhenian and in the Taranto Bay may allow to establish new isochrons to link the different archives thus providing a contribution to the palaeoclimate research for this sector of the central Mediterranean.

New findings of Etna pumice fall deposits on Nebrodi Mountains (NE Sicily) and implications for distal tephra correlations in the Mediterranean area

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Keywords: Etna volcano, Nebrodi Mountains, pumice fall deposits, Sicily.

Intense explosive eruptions took place on Etna in a short period comprised between 15.5 and 15 ka ago generating pumice fall deposits (unit D of Coltelli et al., 2000) and a pyroclastic flow (Biancavilla-Montalto Ignimbrite). These deposits show a composition ranging from benmoreite to trachyte and are considered the products of the Plinian eruptions occurred at the end of the Ellittico volcano activity. Typical localities of the pumice fall outcrops are the East and South-East lower flanks of Etna at Giarre and Acireale, respectively (Branca et al., 2011). Pumice falls beds form two separate couplets in these areas, dispersed south-eastward for the Acireale tephra and eastward for the Giarre tephra (Coltelli et al., 2000).

Recent studies on proximal-distal tephra correlations and synchronisation of Mediterranean archives have outlined the importance of unit D tephra layers as chronostratigraphical tool (Albert et al., 2013; Tomlinson et al., 2015) and has raised issues concerning their correlation with the distal counterparts recovered in marine and lacustrine sediments in different sector of the Mediterranean region. Glass chemistries of distal tephra and chronological constraints indicate a complex series of dispersals from Etna spanning the last glacial-interglacial transition (Albert et al., 2013; Tomlinson et al., 2015). Given that, it is evident that a better knowledge of the dispersal of the individual tephra layer belonging to unit D is needed, especially in those areas not yet investigated.

We report on the stratigraphic data on pumice fall deposits recovered between Floresta and Montalbano Elicona towns in the Nebrodi Mountains and along the Alcantara river close to Randazzo town in the lower northern flank of Etna. We present physical features of the deposits and petrochemical characterization of tephra on the basis of major and trace element composition of matrix glasses. Furthermore, we attempt a tephrostratigraphic correlation with the possible distal counterpart in the Mediterranean area, based on a statistical approach, providing new elements for reconstructing the main explosive events occurred on Etna volcano.

Albert P.G., Tomlinson E., Lane C.S., Wulf S., Smith V.C., Coltelli M., Keller J., Lo Castro D., Manning C.J., Müller W., Menzies M.A. 2013. Late glacial explosive activity on Mount Etna: implications for proximal-distal tephra correlations and the synchronization of Mediterranean archives. J. Volcanol. Geotherm. Res., 265, pp. 9-26.

Branca S., Coltelli M., Groppelli G. & Lentini F. 2011. Geological map of Etna volcano, 1:50,000 scale. Ital. J. Geosci., 130(3), 265-291.

Coltelli M., Del Carlo P. & Vezzoli L. 2000. Stratigraphic constraints for explosive activity in the past 100 ka at Etna Volcano, Italy. Int. J. Earth Sci. 89, 665-667.

Tomlinson E.L., Smith V.C., Albert P.G., Aydar E., Civetta L., Cioni R., Çubukçu E., Gertisser R., Isaia R., Menzies M.A., Orsi G., Rosi M. & Zanchetta G. 2015. The major and trace element glass compositions of the productive Mediterranean volcanic sources: tools for correlating distal tephra layers in and around Europe. Quat. Sci. Rev., 118, 48-66.

Tephrostratigraphy study in the Fucino basin

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Keywords: Tephrostratigraphy, Fucino Basin, Central Italy.

We recovered 6 engine boreholes (down to 7.35 m of depth) from the Fucino basin (Central Italy), an extensional intramountain basin, filled by Pliocene to Quaternary continental alluvial and lacustrine deposits. The study area was the site of Lake Fucino, a large endorheic lake drained at the end of the 19th century. Most of the published data on the Fucino basin derived from on-fault paleoseismic trenching and shallow hand-coring that evidenced ten surface-faulting events in the past 33 kyr (Galadini & Galli, 1999).

All the collected cores were performed both in the present-day depocenter of the Fucino Plain (named "Bacinetto") and close to that area where the longest lacustrine sedimentation record exists. On each core, a Computed Tomography (CT) was performed in order to identify peculiar intervals or sudden changes in the sedimentation, otherwise not easily identifiable through a normal visual inspection. Hence, some selected cores have been then studied extensively to reconstruct paleoenvironment and paleoclimate conditions by means of stratigraphical analysis, magnetic susceptibility measurements and radiocarbon dating. Cores contain several visible tephra layers, microtephra and cryptotephra.

Here, we report on results obtained from the study of S6 core (7.35 cm), which contains the most complete tephrostratigraphic record. In this core, four tephra and five cryptotephra layers have been identified, respectively. Tephra have been sampled and analyzed for texture, mineralogy and major elements chemical composition using the scanning electron microscope (SEM) and the electron microprobe (EMPA-WDS) in the laboratories of the Istituto Nazionale di Geofisica e Vulcanologia. On the basis of texture, mineralogy and geochemical compositions, we have established both the stratigraphic correlations between the cores and between tephra and source eruptions occurred in Holocene and Late Pleistocene from Ischia, Colli Albani and Phlegrean Fields.

Galadini F. & Galli P. 1999. The Holocene paleoearthquakes on the 1915 Avezzano earthquake faults (Central Italy): implications for active tectonics in the central Italy. Tectonophysics, 308,143-170.

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Real-time quadrupole mass spectrometer analysis of fumarolic gas

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Keywords: Pisciarelli, fumaroles, volcanic gas composition, real-time monitoring, geochemistry.

In this work the installation and operation of a system for continuous monitoring of fumarolic gases using a quadrupole mass spectrometer (QMS Pfeiffer Omnistar©) are described. At Pisciarelli site (Campi Flegrei, Southern Italy) several chemical species concentrations were detected in the fumarolic emission with an high sampling rate (very short intervals of measurements down to 1 minute) as well as the fumaroles' temperature. Although numerous technical problems were addressed due to the ephemeral emission point, coupled with the harsh environment, a good statistic record and a reconstruction of the gases evolution of the investigated area was obtained in two different periods (in 2009 and 2012 campaigns). The He/CO_2, H_2S/H_2 and CH_4/CO_2 ratios were used to detect magmatic/hydrothermal component in the system. In fact methane is a gas species which differentiates in hydrothermal systems, where it is present in relatively high concentrations, from high temperature volcanic/magmatic fluids where it is normally absent or present in very low concentrations (Chiodini, 2009; Chiodini et al., 2012). In 2009, our results are comparable to the "classical" sampling methods, but the results are more amplified for the most insoluble species. This is due to a greater precaution to be applied, in the future, to improve water reduction in the sampling-line. Certainly this is a method that allows an high sampling rate, comparable, in the future, with other geochemical data and geophysical aspects of the area. This methodology of continuous monitoring, which provides additional information, e.g. on short-term gas variations than the traditional sampling, allowed us to acquire more frequent data of gas composition in the fumarolic area of Pisciarelli and demonstrated that observing significant short/medium-term geochemical signals, at volcanic-hydrothermal system, is possible. Finally, we believe in the opportunity to develop automatic system of measurements to be installed in the field, and, to performe new experiments, better refining this technique.

Chiodini G. 2009. CO2/CH4 ratio in fumaroles a powerful tool to detect magma degassing episodes at quiescent volcanoes. Geophysical Research Letters, 36, L02302.

Chiodini, G., Caliro S., De Martino P., Avino R. & Ghepardi F. 2012. Early signals of new volcanic unrest at Campi Flegrei caldera? Insights from geochemical data and physical simulations. Geology, 40, 943-946.

Tephrostratigraphy of the DEEP site record, Lake Ohrid (Macedonia/Albania)

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Keywords: Mediterranean tephrostratigraphy, Middle and Late Pleistocene, Lake Ohrid, ICDP project SCOPSCO.

In the central Mediterranean region, tephrostratigraphy has been proofed to be a suitable and powerful tool for dating and correlating of marine and terrestrial records. However, for the period older 200 kyrs, tephrostratigraphy is incomplete, fragmentary and restricted to some Italian continental basins (e.g. Sulmona, Acerno, Merucre), and continuous records downwind of the Italian volcanoes are rare.

Lake Ohrid (Macedonia/Albania) in the eastern Mediterranean region fits this requisite and is supposed to be the oldest continuously existing lake of Europe. Previous tephrostratigraphic studies on short sediment cores from Lake Ohrid identified 11 tephra layers from Italian eruptions of the last 135 kyrs. A continous record (DEEP) was recovered within the scope of the ICDP deep-drilling campaign SCOPSCO (Scientific Collaboration on Past Speciation Conditions in Lake Ohrid). According to inital borehole and core logging data the entire record spans 569 meters composite depth (mcd) and covers more than 1.2 Myrs of Italian volcanism. In the uppermost 450 mcd, as by now 53 tephra layers were identified during core-opening and description.

A first tephrostratigraphic record was established for the uppermost 248 mcd (~637 ka). Major element analyses (EDS/WDS) were carried out on juvenile glass fragments and 13 out of 34 tephra layers have been identified and correlated with known and dated eruptions of Italian volcanoes. They include the Mercato tephra (8.43–8.63 ka cal BP), Y-3 (26.68–29.42 ka cal BP), the Campanian Ignimbrite or Y-5 (39.6±0.1 ka), TM24a/POP2 (102±2 ka), X-6 (109±2 ka), P-11 (133.5±2 ka), Vico B (162±6 ka), CF-V5/PRAD3225 (163±22 ka), Pozzolane Rosse (457±2 ka), SC5 (493.1±10.9 ka), Fall A (496±3 ka), A11/12 (511±6 ka), and Tufo di Bagni Albule (527±2 ka). Excisting $^{40}Ar/^{39}Ar$ ages were re-calculated by using the same flux standard (1.194 Ma for ACs, which corresponds to FCs at 28.02 Ma) in order to obtain a homogenous set of ages. The tephrochronological information was then used as first order tie points to develop a robust chronology for the DEEP site succession.

Additional analytical work (e.g. trace elements, isotopes) will help to improve and establish proper correlations of Ohrid tephras with the relevant Italian volcanic provinces and their specific eruptions. Between 248 and 450 mcd of the DEEP site succession, another 18 tephra horizons were identified and are subject of ongoing work. These deposits, once correlated with their specific eruptive origin, will hopefully enable dating this part of the succession, likely supported by major paleomagnetic events such as the Brunhes-Matuyama boundary, or the Cobb-Mountain or the Jaramillo excursions. This makes the Lake Ohrid record a unique continuous, distal record of Italian volcanic activity, which is candidate to become the template for the central Mediterranean tephrostratigraphy, especially for the hitherto poorly known and explored lower Middle Pleistocene period.

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Combined geochemical and isotopic analyses as a tool for identifying tephrostratigraphic markers in distal sequences of Middle-Upper Pleistocene

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Keywords: Tephrostratigraphy, Stratigraphic markers, Geochemical fingerprints, Sr-Nd isotopes.

In the last few decades, attribution of tephras collected from continental and marine sequences to widespread pyroclastic deposits of known age has been successfully achieved through a geochemical characterization based on major and trace element abundances. Only in few cases, radiogenic isotopes analysis has been applied to tephra layers for identification purposes. These analyses are generally limited by the scarce amount of available fresh glass, and the consequent need for a clean lab where tiny samples can be handled avoiding their contamination, as well as for high-precision mass spectrometry facilities. Furthermore, water alteration could affect glass shards collected from cores to a variable extent. This might preclude obtaining reliable isotope ratio values, especially $^{87}Sr/^{86}Sr$. Radiogenic isotopes, on the other hand, represent a valid support to the geochemical fingerprinting of distal tephras. This is especially true when geochemically and isotopically well characterized proximal deposits are available for comparison. Geochemical and Sr-Nd-isotopic analyses were carried out on twenty primary tephra layers, embedded in lacustrine sediments of the San Gregorio Magno basin (Southern Apennines) and several tephra layers from six deep-sea cores, recovered between the Ionian and the Aegean Seas. The aims of this investigation are: i) testing the reliability of Sr and Nd isotope ratios determination on glass shards selected from tephra layers already identified from the stratigraphic viewpoint, and ii) identifying the geochemical affinity and geodynamic setting of tephras of dubious attribution in order to associate them to already known tephra markers. A careful selection of ash fragments, a prolonged leaching procedure with high-purity hydrochloric acid, high precision and accuracy major oxides, trace elements content, and Sr-Nd-isotope ratios measurements were performed. The Sr isotopic composition of volcanic ashes collected from the lacustrine core does not seem affected by alteration, a strong problem for marine layers, which in many cases yielded measured $^{87}Sr/^{86}Sr$ values higher than expected. However a repeated acid-leaching resulted in a lowering of $^{87}Sr/^{86}Sr$, significantly reducing the sea water contamination effect. Conversely, the $^{143}Nd/^{144}Nd$ value, unaffected from alteration, has proven to be the most efficient parameter for tephra identification. The results of this study suggest that the combination of major oxides, trace elements and Sr-Nd isotopic data, supported by stratigraphic, volcanic and geochronological information, provides an accurate attribution of tephra layers found in marine and continental cores to past high-size eruptions, enabling us to better contour the emplacement area of their products, thus supplying further hints to assess volcanic hazard.

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The Neapolitan Yellow Tuff tephra in the stratigraphic architecture of the Gulf of Gaeta shelf, eastern Tyrrhenian margin

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Keywords: Neapolitan Yellow Tuff, Phlegraean Fields, stratigraphic signature, gravity cores.

The Neapolitan Yellow Tuff (NYT) caldera-forming eruption (ca. 15 ka; Deino et al., 2004) is a large event occurred at Phlegraean Fields during the late Pleistocene-Holocene. The eruptive products represent a widespread isochron marker which links marine and terrestrial archives of the central Mediterranean area and northern Europe. In this research we describe the stratigraphic signature of the NYT deposits in the Late Pleistocene-Holocene shelf sequence of the Gulf of Gaeta (northern Campania region, southern Tyrrhenian sea) by using a number of gravity cores along with a grid of high and very high-resolution seismic lines.

The Gulf of Gaeta represents the northern Campania continental margin that is part of a large extensional Plio-Pleistocene basin associated with normal and strike-slip faults linked to the evolution of the eastern Tyrrhenian Sea margin. Since mid-late Pleistocene, extensional tectonics took place across the continental margin and it was accompanied by intense volcanism, from several districts of which the Phlegraean Fields activity has greatly influenced the sedimentation in this sector. The continental shelf, gently sloping seaward, is as wide as 30 km in front of the Garigliano river and narrows southward reaching its minimum width of ca. 10 km seaward of Cuma; the shelf break is located between 120 m and 125 m depth. The upper Pleistocene-Holocene stratigraphic architecture of the continental shelf is characterized by an offlap prograding succession followed by a very thick transgressive onlapping unit and by the upper highstand unit mainly characterized in the southern sector by undulations probably linked to gas prone sediment. The slope is characterized by a uniform profile and, in the southern sector, it is incised by several submarine gullies. According to Chiocci and Casalbore (2011), the high thickness of sediment on the shelf and slope area was influenced by hyperpycnal flows, linked to the sudden and large supply of pyroclastic and volcaniclastic deposits in the Volturno river catchment basin.

In the studied seismic sections, the NYT matches a highly continuous and parallel reflector which is interbedded within the transgressive systems tract deposits. The deposit was recovered in cores raised from the slope, where it is present few milliseconds below the sea floor, while on the shelf where it is located at higher depths, ranging from 10 to 30 ms (8 to about 25 m) below sea floor, has been mapped out through the seismic lines. The tephrostratigraphic analysis allowed to characterize the NYT in terms of lithology and chemistry and to provide new insights into the depositional mechanisms in the marine environment.

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Implications of the recent results on the $^{40}Ar/^{39}Ar$ single crystal dating of tephras in the Apennines basins and further

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Keywords: Quaternary, Intermontane depressions, $^{40}Ar/^{39}Ar$, Volcanism, Tephras, Apennines.

Geologically, the central and southern part of the Italian peninsula is unique in Western Europe. Intermontane depressions belonging to the system of grabens or semi-grabens that were developed along the Apennines since the late Pliocene are exceptional Quaternary archives. The study of the sedimentary infilling of these tectonic basins as well as the continental marginal basin of the Roman area is relevant for a number of scientific issues including active tectonics, palaeo-climatology, palaeo-environment, Quaternary stratigraphy and archaeology. As all these scientific issues have in common to require a reliable chronological framework. Fortunately, the recurrent and long-lasting explosive activity from the peri-Tyrrhenian Quaternary volcanic centres makes the central Apennines region one of the few places on Earth, like East Africa, where Quaternary geological archives contained a self-consistent a reliable chronological framework thanks to widespread ash layers.

Since now about 5 years in the frame of an Italian-French collaboration including several Italian institutions (i.e. IGAG-CNR Rome; Univ. Pisa; INGV Roma; Univ. Ferrara; Univ. Firenze) we initiate several multidisciplinary investigations focused on the central and southern Apennines basins. One of the key points of all of these projects was to use well-dated tephras markers as tools to build robust and independent chronological frameworks as well as synchronizing Quaternary archives. Our projects lead to significant results and for numerous scientific issues including palaeo-climatology, palaeo-environment, stratigraphy, palaeomagnetism as well as archaeology covering the last 800 ka. After a brief presentation of the $^{40}Ar/^{39}Ar$ method and its current limitations and advantages, we will illustrate some of the results obtained over the last 5 years.

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X-ray computed microtomography investigation of pyroclastic rocks of the Pomici di Base plinian eruption

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Keywords: microtomography, magma degassing, explosive eruption.

The study of the texture of volcanic rocks (shape, size and distribution of vesicles and microlites) provides fundamental information about the eruptive dynamic. In fact, the mechanism and timescale of crystallization and degassing during magma ascent in the volcanic conduit, control its rheological properties (e.g., viscosity) and hence have a strong influence on eruptive style. Detailed investigations, therefore, on the texture of the pyroclastic rocks are crucial to the understanding of sub-volcanic processes that are closely related to the evolution of geochemical and geophysical parameters recorded at the surface from the monitoring network during the pre-eruptive crisis.

The X-ray microtomography is a non-destructive analysis technique that offers the opportunity to visualize and quantify the internal structure of rock samples by generating three-dimensional digital maps with a very high resolution of up to submicron.

We present the results of a textural study of rocks emitted during the Pomici di Base eruption, representing the first plinian event of the Somma-Vesuvius volcano. The obtained 3D textural data have played a key role in the interpretation of the magma rising mechanism in the conduit, allowing the direct observation, of the orientation and shape of the vesicles, as well as of the degree of interconnectedness and permeability that strongly influence degassing and fragmentation processes, and that are inaccesible by using the more conventional 2D techniques.

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Contribution of the $^{40}Ar/^{39}Ar$ method to the chronology of some Middle Pleistocene Italian archaeological sequences

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Keywords:40Ar/39Ar dating; tephras; Middle Pleistocene; pre-Neanderthal evolution.

Evolution and dispersion of Pre-Neanderthal populations in Western Europe are heavily debated topics. The current lack of knowledge is mainly due to the low number of archaeological sites but also to the difficulties that archaeologists faced to provide accurate chronological constraints, essential to the elaboration of evolutionary schemes. Several dating methods are relevant for the Middle Pleistocene period, between 780 and 128 ka, but they are all dependant of specific geological conditions that prevent most of the time their concurrent use. The Italian peninsula is then characterized by an intense and regular volcanic activity that led to the deposition of ash falls (tephras) or to the presence of reworked volcanic materials within sedimentary sequences including archaeological ones. Tephras layers are among the best geochronological markers because they are chemically characteristic of a volcanic edifice or sometimes of a specific eruption. Their occurrence into stratigraphic sequences offers also the possibility, in addition to other methods (ESR, ESR/U-series, TL), to use the $^{40}Ar/^{39}Ar$ on single-crystal approach, one of the most accurate dating technics available for this timescale. This radio-isotopic method, based on individual analyses of K-feldspars minerals (sanidines, leucites), provides direct age for archaeological layers, when the latters are embedded within a primary volcanic deposit, or at least gives a good chronological framework when these tephra layers are included within a continuous stratigraphy. Another advantage of this technic is the highlighting and dating of a corpus of volcanic eruptions recorded within fluvial reworked layers, giving also essential chronological information about the age of the deposit. Central and Southern Italy, that housed a large number of archaeological sites throughout the Middle Pleistocene, is thus a privileged study territory for both geochronology and human evolution. To illustrate the potential of the $^{40}Ar/^{39}Ar$ method for the dating of Middle Pleistocene Italian sites and its contribution to the comprehension of the Neanderthal lineage in Europe, results obtained, for a corpus of key Middle Pleistocene sites such as Isernia la Pineta (Molise), La Polledrara di Cecanibbio (Latium) or Notarchirico (Basilicata) will be displayed and discussed.

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Stratigraphy and reconstruction of the last caldera-collapse eruption of Sete Cidades Volcano (São Miguel, Azores): the ~16 ky Santa Bárbara Formation

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Keywords: Sete Cidades, caldera-eruption, pyroclastic density currents, magma mingling.

Sete Cidades is an active volcano located in the westernmost part of São Miguel Island (Azores). Its summit is characterized by a complex caldera with a diameter of about 5 km, formed in the last 36 ky. In this work we present new stratigraphic, granulometric, petrographic and geochemical data related to the last caldera collapse event, called Santa Bárbara eruption. The architecture, distribution and thickness of the investigated deposits are spatially organized around the Sete Cidades caldera. The maximum preserved thickness of the Santa Bárbara sequence is more than 10 m on the north-eastern flank. The maximum horizontal distance between today's morphological caldera rim and the coast is less than 5 km. Accordingly, only a small fraction of the eruptive products has been deposited on land. We have estimated that the related outcropping deposits amount to ~0.1 km^3. The preserved deposits are entirely non-welded and dominated by massive, lithic-rich lapilli tuffs emplaced by variably energetic pyroclastic density currents (PDCs) and locally thick but volumetrically subordinate pumice fall deposits. The eruption was supposedly triggered and fed by magma mingling following the intrusion of trachybasalt magma into a trachytic magma reservoir, as demonstrated by diffuse presence of juvenile mafic enclaves inside pumice clasts. Geochemical analyses indicate a dominant trachytic composition of the magma (63 wt% SiO_2), with small mafic enclaves of trachytic-basalt (47 wt% SiO_2) composition. Textural and lithofacies characteristics of the Santa Bárbara pyroclastic sequence suggest that the eruption started with highly energetic dilute PDCs that deposited mainly the S-SW part of the volcanic edifice. This event produced the deposition of less than 1 m of well-stratified lapilli and ash tuffs. Textural results on juvenile fractions of different surge layers demonstrate that magma-water interaction was absent or negligible. The climax of the Santa Barbara eruption was marked by frequent collapses of the eruptive column leading to laterally spreading PDCs that emplaced lithic-rich, massive ignimbrite, presumably accompanied by partial collapse of the volcanic edifice. Towards the end of this, sub-Plinian eruption, energy waned and a coarse pumice- and lithic-rich fallout deposit was generated. Based on the distribution of the fall deposits, we conclude that fairly strong south-westerly winds were blowing. This study contributes to give useful insights about violent explosive eruptions of Sete Cidades Volcano in the densely populated island of São Miguel.

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Temporal and spatial evolution of the sustained Campanian Ignimbrite Plinian plume as revealed by internal architecture of the fall deposit

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Keywords: Plinian, fall deposit, Campanian Ignimbrite, Campi Flegrei, eruption parameters, dispersal.

The Campanian Ignimbrite eruption is considered one of the most powerful ultra(?)-Plinian eruptions in the Mediterranean area in the last 200 k.y. We have established a new stratigraphy for the products of the basal fall deposit (Plinian pumice fall) associated with the Campanian Ignimbrite eruption, based on detailed field work in the Campanian region (Scarpati & Perrotta, 2016). We recognize a thick and coarse pyroclastic horizon along the Campi Flegrei caldera rim as the proximal facies of the fall deposit and correlate this proximal deposit with five different layers recognized in 45 locations up to 80 km from the source area. The fall deposit displays internal stratification and strong size grading; it is divided into different layers on the basis of grain size, component variations, and graded bedding. Stratigraphic details of the Plinian deposit differ azimuthally and also change with distance from the source. The medial Plinian fall deposit of the Campanian Ignimbrite consists of five layers, designated as A to E from the base to the top. This sequence is capped and extensively eroded by the ignimbritic succession (Scarpati & Perrotta, 2012). In order to quantify lateral and vertical changes granulometry, juvenile density and components were performed on about 130 samples. By combining the structure of the fall deposits with newly calculated column-height variations and durations, we are able to evaluate plume (ascending or descending) velocity and its influence on stratification and grading. All Campanian Ignimbrite fall layers, display Plinian dispersal. We interpret the presence of lobes in the isopachs along the southern boundary of both layer B top and layer D base as reflecting a wind shift over the course of the eruption. We suggest that the sharp boundaries between the different layers, as observed in medial and on axis sections, represent the result of rapid variations in column height. When variation in column height is slow the resultant deposit is respectively reverse or normal graded. Calculations including distal ash provide a more complete volume of coeval Plinian and co-Plinian phases of 20 km^3. We can refine eruption duration estimates to ~20 h by considering total Plinian and co-Plinian volume and assuming an average MDR (mass discharge rate) of 2.6×10^8 kg/s during deposition of layers A to E. Using a 20 h duration we calculate: a) VEI rises to 6; b) plume velocities during the ascent and descent oscillations decrease from ~4 m/s to ~1 m/s; and (3) accumulation rates where the load pressure can cause destruction to properties decrease in the range from 10 cm/h to 2.5 cm/h.

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Tephra dispersal during the Campanian Ignimbrite (Italy) eruption: Implications for ultra-distal ash transport during the large caldera-forming eruption

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Keywords: Campanian Ignimbrite, caldera-forming eruption, ash dispersal, co-PDC, Plinian, tephra.

The Campanian Ignimbrite eruption dispersed ash over much of the central eastern Mediterranean Sea and eastern Europe. The eruption started with a Plinian phase that was followed by a series of pyroclastic density currents (PDCs) associated with the collapse of the Plinian column and the caldera. The glass compositions of the deposits span a wide geochemical range but the Plinian fallout and PDCs associated with column collapse, the Lower Pumice Flow, only erupted the most evolved compositions. The later PDCs, the Breccia Museo and Upper Pumice Flow, erupted during and after caldera collapse, tap a less evolved component, and intermediate compositions that represent mixing between the end-members. The range of glass compositions in the Campanian Ignimbrite deposits from sites across the central and eastern Mediterranean Sea allow us to trace the dispersal of the different phases of this caldera-forming eruption. We map the fallout from the Plinian column and the plumes of fine material associated with the PDCs (co-PDCs) across the entire dispersal area. This cannot be done using the usual grain-size methods as deposits in these distal regions do not retain characteristics that allow attribution to either the Plinian or co-PDC phases. The glass compositions of the tephra at ultra-distal sites (>1500 km from the vent) match those of the uppermost PDC units, suggesting that most of the ultra-distal dispersal was associated with the late co-PDC plume that was generated during caldera collapse.

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Pre-caldera eccentric vents at Somma-Vesuvius: scoria and spatter cones near Pollena Trocchia

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Keywords: Somma-Vesuvius, eccentric vents, Pollena Trocchia, lava-like deposits.

Somma-Vesuvius is well known for its large plinian eruptions that destroyed villages and buried land in a wide area around the volcano. Nevertheless, effusive or weakly explosive flank eruptions also occurred forming eccentric cones. This activity poses serious hazard due to their proximity with human activities (villages, farms, roads). Thanks to a quarry exposure on the northern slope of Somma-Vesuvius, near the village of Pollena Trocchia, two well-preserved cones have been studied in detail. These cones were previously described as formed by a succession of coarse scoria beds intercalated by lavas (Franco and Rolandi, 1979). The first scoria cone is situated at ~270 m a.s.l. and its morphology appears less preserved than the second scoria cone. The cone has a height (H) of ~40 m, a minimum basal width (W_{co}) of ~320 m and a crater width (W_{cr}) of ~40 m. The estimated minimum volume is 1.22 x 10^6 m^3 and the H/W_{co} ratio is 0.13. The lower part of the cone is composed of scoria lapilli, massive to crudely stratified and well sorted. This deposit is overlaid by a thick stratified succession of scoria lapilli and blocks and lava-like layers formed by welded and agglutinate spatters. The second scoria cone is situated at ~245 m a.s.l., in the lower part of the quarry. It is the smallest of the two scoria cones with a height (H) of ~21 m, a minimum basal width (W_{co}) of ~120 m and a crater width (W_{cr}) of ~15 m. The estimated minimum volume is 6.66 x 10^5 m^3 and the H/W_{co} ratio is 0.18. The stratigraphy of the second scoria cone can be arranged in two parts, separated by a paleosoil, allowing to identify two distinct cone-forming eruptions. The lower part of the cone is composed of reddish scoria lapilli and abundant blocks of fall origin. The upper part of the cone is composed of an alternation of two scoria fall deposits and two lava-like beds covered by pyroclastic density current deposits. In the upper part of the Pollena quarry, the deposits of the first scoria cone are mantled by the plinian fall deposit belonging to the Pomici di Base eruption. This observation allows to assign this activity to a pre-caldera period. Our field-based study explore the nature of the previously recognised lavas. These horizons pass laterally and vertically to pyroclastic deposits (mainly spatter and scoria beds). This transition strongly suggests the occurrence of a weakly explosive activity that produced welding of coarse and hot clasts (spatters) that, fell from limited height, travelled on relatively low paths with limited in-flight cooling. The high temperature of emplacement has resulted in a flattening and welding of clasts, that locally produced lava-like structures.

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Tephrochronology of a ~ 70 ka-long marine record in the Marsili Basin (southern Tyrrhenian Sea)

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Keywords: Tyrrhenian Sea, oxygen stratigraphy, tephra, Aeolian Arc, Brown Tuffs, Y-1, Y-6, Y-7.

Several discrete tephra layers are studied in a 13.9 m-long deep-sea core (MD01-2474G) from the southern Tyrrhenian Sea. Major, minor and trace element data (EMPA-WDS and LA_ICP-MS analyses) on fresh micro-pumices or glass shards were obtained from selected tephras correlated with the volcanic activity of Aeolian Arc (Vulcano and Salina), Mt. Etna, Phlegrean Fields Pantelleria and Ischia. The chronology of the succession is provided by a high-resolution age-depth model based on isotope stratigraphy and AMS radiocarbon dating, which place the succession of events in a time interval spanning the last 70 kys BP. Based on a precise chronological framework and a detailed proximal-distal correlation, the Y-1, Y-6 and Y-7 main marker tephras were identified. In addition, the sequence contains a number of deposits documenting a recurrent activity of Vulcano Island at ca. 6.9 ka BP (MD3), ca. 16.7 ka BP (MD11), ca. 23.2 ka BP (MD14), ca. 29.6 ka BP (MD15), ca. 36.9 ka BP (MD22) and ca. 42.5 ka BP (MD27). The results presented in this study aim to contribute to the southern Tyrrhenian Sea tephrostratigraphic framework tephrochronology and contribute to provide new insights into chemistry and dispersal area of Aeolian Arc pyroclastic in this sector of the Central Mediterranean.

Late Pleistocene-Holocene tephrostratigraphic record from Southern Adriatic Sea

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Keywords: Tephra, Adriatic Sea, Somma-Vesuviius, Campi Flegrei.

A tephrostratigraphic investigation was carried out on the composite marine record ND_14Q raised in July 2014 from the Southern Adriatic Sea to the east of the Gargano promontory, from a water depth of 1013 m b.s.f. Magnetic susceptibility peaks revealed the presence along the cored succession of several cryptotephras, ranging in thickness between 2 and 12 cm, that were sampled and analysed in terms of lithology and major element glass chemistry. The analysed samples cluster into two main compositional groups, one straddling the boundary between trachyte and phonolite fields, the second ranging from phonotephrites to phonolites. These compositions point to Campi Flegrei and Somma-Vesuvius sources, respectively. Along with some tephras already reported for the study area by Siani et al. (2004) and Matthews et al. (2014), preliminary results for core ND_14Q pinpoint the occurrence for the first time in the Adriatic Sea of the 1631 and 79 AD distal counterparts. Moreover, a Somma-Vesuvius related tephra comparable in composition to the Mercato (ca. 9 ky B.P. - Santacroce et al., 2008) deposits was found immediately above the Agnano Pomici Principali (ca. 12 ky B.P. - Smith et al., 2011) tephra, enabling us to hypothesize the occurrence of explosive activity at the volcano between Greenish (ca 19 ky B.P. - Santacroce et al., 2008) and Mercato eruptions. The proximal-distal correlations established in this study provided several tie points that chronologically constrain a continuous record with no or little disturbance, which makes the ND_14Q sequence very suitable for paleoenvironmental and paleoclimate researches.

This research has been financially supported by the Project of Strategic Interest NextData PNR 2011-2013 (www.nextdataproject.it)

Matthews I.P., Trincardi F., Lowe J.J., Bourne A.J., MacLeod A., Abbott P.M., Andersen N., Asioli A., Blockley S.P.E., Lane C.S., Oh Y.A., Satow C.S., Staff R.A. & Wulf S. 2014. Developing a robust tephrochronological framework for Late Quaternary marine records in the Southern Adriatic Sea: new data from core station SA03-11. Quatern. S. Rev., 118, 84-104.

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Mediterranean tephrostratigraphy and Late Quaternary environmental changes

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Keywords: Tephras, Mediterranean, Explosive activity, Quaternary.

With the explosion of palaeoclimatic and palaeoenvironmental researches following the concerns related to global warming, few volcanologists could have imagined their role to have changed so dramatically from their traditional focus. In the last two decades, this sector of the scientific community was compelled to move towards a tighter link with Quaternarists, geomorphologists, archaeologists, palaeoceanographers and more in general palaeoclimatologists. Tephrostratigraphy and the identification of tephra layers in different archives will become a mandatory request of many projects for synchronizing archives and improving chronological control of palaeoclimatological records.

The Mediterranean basin is probably one of the most significant areas globally where tephrostratigraphy can reveal its full potential and benefit different disciplines, due to the very large number of explosive volcanoes with very distinctive geochemistries. In this presentation will be highlighted several examples in which tephra layers can used to solve correlation between archives and the precise identification of paleoclimatic events. Outstanding examples of application of tephrostratigraphy in the Mediterranean basin will be discussed from the Holocene (e.g. Zanchetta et al., 2012), to Upper-Middle Pleistocene (Giaccio et al., 2015a, 2015b, Regattieri et al., 2016; Leicher et al., 2016).

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SESSION S24

Volcanic and seismic hazard monitoring: from field data to numerical modelling through remote sensing

CONVENERS AND CHAIRPERSONS

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Eruptive and source mechanisms at Etna volcano from strain detected by the borehole dilatometers network

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Keywords: Etna volcano, eruptions, euptive mechanims, strain monitoring, borehole strainmeters.

A network of 4 borehole dilatometers has been installed on Etna in two successive phases (2010-2011 and 2014). The instruments, installed in holes drilled at depths between 100 and 200 m, are able to measure the volumetric strain of the surrounding rock with a nominal precision up to 10^{-11} in a wide frequency range (10^{-7} – 10^{2} Hz). During the lava fountains erupted from 2011 to 2015 strain changes were detected. Analytical and numerical computations constrained the eruptions source depth, and also its volume change that is related to the magma volume emitted. The source volume change can be related to magma volume emitted during the eruptive activity, therefore allowing the estimation of the total erupted volumes.

Moreover, we show how this volume estimation can be also used to evaluate the balance between expected and erupted magma volumes at Etna volcano. This proposed approach provides an useful tool for predicting, for a given time frame, the maximum volume that an ongoing eruptive activity will emit to reach the equilibrium or that will be erupted by a potential new eruptive.

Preliminary results on how strain changes can contribute to constrain the gas and pyroclastic contents for each eruptive event are also presented. This method could be used to evaluate the trend of the explosivity degree during an eruptive sequence.

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Innovative volcano and multi-hazard monitoring systems at Osservatorio Vesuviano-INGV

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Keywords: Volcanoes, Monitoring Systems, Numerical Analysis, Opto-electronics.

The Neapolitan volcanic area is characterised by the highest volcanic risk in the World, due to its intense urbanisation coupled with the co-existence of three explosive volcanoes within less than 20 km distance one another: Vesuvius, Campi Flegrei caldera and Ischia Island. About 3.5 millions peaople live to within 10-15 km of distance from a volcanic vent.

The Osservatorio Vesuviano, department of Naples of the Italian Institute for Geophysics and Volcanology, is officially in charge of the monitoring and surveillance of this extreme risky area, which also involves seismic and landslide risk linked to volcano-tectonic activity.

In the last 2.5 years, Osservatorio Vesuviano has largely improved its monitoring systems, also developing new concepts of multi-hazard monitoring systems, implemented as prototypes. The new installations aims to maximise the information on the volcanic and other hazardous processes, together with the signal to noise ratio in this very densely urbanised (and then noisy) area. In the meantime, the increased amount of information is suitable of accurate numerical modeling in order to significantly improve our knowledge about the detailed volcano-tectonic processes and their possible evolution towards catastrophic events.

This work reports on the most significant improvements of the monitoring and surveillance systems, which basically followed three main lines: development of borehole sensing networks, development of marine and coastal monitoring, re-organisation of the activities in the Monitoring Room. A further step, just started, is the improvement of the geochemical continuous sensing with innovative technologies, actually the less developed part of the monitoring system despite its key role for understanding magmatic and pre-eruptive processes. Some examples of refined numerical treatment of such data for volcano modelling are also reported.

The strong improvement of the monitoring system has been made possible by an accurate and well focused management of several applied research and infrastructural projects, the main one are CFDDP (Campi Flegrei Deep Drilling Project) funded by ICDP and EU FPVII-GEISER; PON-MONICA and PON-VULCAMED granted by the Ministry of Research with European funds; MIUR-ITEMS, funded by the Ministry of Research with National funds.

One of the most innovative technologies, largely implemented in several new installations, is based on the opto-electronic concepts (Brillouin effect and Bragg's gratings).

Gas output rate from fumaroles and bubbling pools: combining Tunable laser technique and a Lagrangian dispersion model

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Keywords: fumaroles, bubbling pools, mud volcano, La Fossa volcano, Mt Etna, Sicily.

We report on the measurements of the output rate of CO_2, H_2S, H_2O and SO_2 from the fumarolic plume of La Fossa volcano (Aeolian Island) and CO_2 from a mud volcano at the periphery of Mt Etna. The method we have applied is based on the measurements of path-integrated gas concentrations in atmosphere at 0.5-1 m from the soil, by using the diode tunable lasers (GasFinder Boreal Europe Ltd.). Once obtained the in-plume concentration, we apply a Lagrangian Stochastic (LS) model to simulate the transport of gases from single or composite sources and retrieve the gas output rate.

We present the first measurements of gas flux from several bubbling mud pools in a mud volcano located in the village of Paternò (Lon 14.89° Lat 37.57°), in the southern flank of the volcano, from February 2014 to April 2016. These volcano-sedimentary manifestations drain both gases and hot saline water from the underlying hydrothermal system. The gas emitted consists mainly of CO_2, with CH_4, N_2 and He as minor species. Gas chemistry and CO_2 and He stable isotopes indicate a clear magmatic origin for these gases and re-equilibration at hydrothermal conditions. Their compositional changes during either eruptive or rest periods closely parallel that of crater fumaroles (Paonita et al., 2012). Altough these manifestations are the most significant CO_2 emitters outside the crater area, their mass output has never been measured.

The remote measurements of CO_2 and H_2S with the specific tunable laser have been performed in 2015 in the crater area of La Fossa volcano. At La Fossa volcano, with the exception of the direct measurements of the steam output from fumaroles performed from 1983 to 1995, the mass output of the single gas species has been recently measured, with various methods, only sporadically or for short periods (Aiuppa et al., 2006; Pedone et al., 2014). In this work, the fluxes of CO_2 and H_2S have been computed by applying the Lagrangian dispersion model on data of atmospheric concentrations obtained with the Tunable lasers; the fluxes of H_2O and SO_2 have been retrieved from the CO_2/H_2O and CO_2/SO_2 concentration ratios, derived from the mapping of the fumarolic field with a Mutigas analyzer.

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Risk management from space: achievements and indications by the pilot projects on Seismic and Volcanic hazards of the Committee for Earth Observation Satellites (CEOS)

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Keywords: risk management, seismic and volcanic hazards, Earth Observation Satellites.

In 2014 the Committee on Earth Observation Satellites (CEOS), created by G8, launched four thematic Pilots Projects on Seismic, Volcanic and Flood hazards, which will be followed soon by a fourth pilot on landslides. These activities aim to showcase innovations in the application of satellite data to full-cycle Disaster Risk Management (DRM), and show how institutional users can overcome challenges associated to accessing and exploiting satellite-borne information to support hazard mapping, risk assessment and event monitoring at all temporal and spatial scales. Both Pilots operate in support to to the Geohazard Supersites and Natural Laboratories (GSNL), in terms of data and model provision
The Seismic Hazard Pilot's broader objective is to demonstrate how satellite EO can be used to improve geodetic monitoring of faults and the earthquake cycle, and provide scientific information to support the response to seismic events. Specific targets are to support: (i) the generation of globally self-consistent strain rate estimates, (ii) the mapping of active faults at the global scale, and (iii) the development of advanced science products for rapid response to earthquakes of medium to large Magnitudes.

The Volcanic Hazard Pilot focuses on the operational monitoring in support to risk and emergency management at supra-continental scale, involving the whole of Latin America and the Caribbean both on ground and in the atmosphere. The pilot is organized on two main objectives: (iv) Demonstrate the feasibility of global volcano monitoring of Holocene active volcanoes using satellite EO to detect, measure and track ground deformation and thermal, gas, and ash emissions; and (v) carrying out specific studies in case of a major eruption with significant regional or global impact, providing data for a comprehensive analysis of all aspects of the eruption cycle, including local, regional, and global impacts, both in delayed-time and in near-realtime.

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Quantifying uncertainties in satellite observations and their propagation in the numerical modeling of effusive scenarios

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Keywords: HOTSAT system, MAGFLOW model, lava flows, numerical simulations.

Lava flow emplacement is sensitive to aspects such as effusion rate, the changing rheology of molten lava as it cools down-flow, and topographic attributes of the terrain. This sensitivity is reflected in physics-based models and their sensitivity to uncertainties in the input parameters, so that propagation of errors through a simulated flow may have a significant effect on its accuracy and reliability. One of the main parameter controlling the final length of the flow is the effusion rate, that is often retrieved by satellite data in the form of time-averaged discharge rate (TADR). The satellite processing involves multiple steps: (i) calibration, (ii) atmospheric correction, (iii) detection of thermal anomalies (i.e. hotspot detection), (iv) radiative power computation and (v) TADR estimation. Each of these steps is affected by uncertainties, which propagate throughout the whole process. We here evaluate the uncertainties in satellite-derived products obtained by the HOTSAT thermal monitoring system, focusing on how these uncertainties reflect on TADR estimation, and finally their impact in lava flow simulations by the MAGFLOW physics-based model. We compute the uncertainty due to the detection of hotspots, that includes possible false alarms and missed identifications, and uncertainties due to the radiant heat flux computations and TADR estimation. In particular we take into account the contribution of the topography with respect to the satellite view angle and the cloud coverage. To evaluate these effects, three different kinds of well documented eruptions occurred at Mt Etna are taken into account: a short-lived paroxysmal event, i.e. the 11-13 Jan 2011 lava fountain, a long lasting eruption, i.e. the 2008-2009 eruption, and a short effusive event, i.e. the 14-24 July 2006 eruption.

Long-term RST analysis of anomalous sequences of Earth's thermal emission, measured by TIR satellite sensor, in relation with earthquakes occurred in Turkey in the period 2004-2015

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Keywords: Robust Satellite Techniques (RST), TIR anomalies, Short-term seismic hazard assessment, Earthquake.

Real-time integration of multi-parametric observations is expected to accelerate the process toward improved, and operationally more effective, systems for time-Dependent Assessment of Seismic Hazard (t-DASH) and earthquake short term (from days to weeks) forecast. However a very preliminary step in this direction is the identification of those parameters (chemical, physical, biological, etc.) whose anomalous variations can be, to some extent, associated to the complex process of preparation of major earthquakes. In this paper one of these parameter (the Earth's emitted radiation in the Thermal Infra-Red spectral region) is considered for its possible correlation with M≥4 earthquakes occurred in Turkey in between 2004 and 2015. The RST (Robust Satellite Technique) data analysis approach and RETIRA (Robust Estimator of TIR Anomalies) index were used to preliminarily define, and then to identify, Significant Sequences of TIR Anomalies (SSTAs) in 12 years (1 April 2004- 31 October 2015) of daily TIR images acquired by the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the Meteosat Second Generation (MSG) satellite. Taking into account physical models proposed for justifying the existence of a correlation among TIR anomalies and earthquakes occurrence, specific validation rules (in line with the ones used by the Collaboratory for the Study of Earthquake Predictability - CSEP - Project) have been defined to drive a retrospective correlation analysis process and to characterize the predictive value of such observations. The analysis shows that more than 67% of all identified SSTAs occur in the pre-fixed space-time window around the occurrence time and location of earthquakes (M≥4), with a false positive rate smaller than 33%. Moreover, to better qualify the possible contribution of the use of SSTAs in the framework of a multiparametric system for a t-DASH, a Molchan error diagram analysis was applied in order to verify the actual SSTAs added value in comparison with a random alarm function. Notwithstanding the huge amount of missed events due to frequent space/time data gaps produced by the presence of clouds over the scene the achieved results, and particularly the low rate of false positives registered on a so long testing period, seems sufficient (at least) to qualify TIR anomalies (identified by RST approach and RETIRA index) among the parameters to be considered in the framework of a multi-parametric approach to time-Dependent Assessment of Seismic Hazard (t-DASH).

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Ten years of observations of the thermal regime of Low Temperature Fumaroles (LTF, t<100 °C): state of the art, results and perspectives

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Keywords: Fumarole, Monitoring, Temperature.

Fumaroles are emissions of water vapour associated to other gaseous species of hydrothermal and/or volcanic origin, both in sub-aerial and underwater environments. According to their emission temperature they are defined as High (HTF, t>100°C) or Low (LTF, 100°C> t) Temperature Fumaroles. Fumarole temperature monitoring is an useful tool in the evaluation of volcanic activity, since it highlights variations related to the discharge rate of deep and hot gases.

In addition to the volcanic signal, two other processes are able to influence the thermal regime of fumaroles: permeability changes, due to the dynamics of the stress field acting both at local and regional/sub-regional scales on a volcanic edifice, and infiltration of meteoric waters. Whilst the latter represents an environmental noise, stress-induced thermal anomalies are of great interest in monitoring programs, because they are the surface evidence of the tectonic dynamics that may influence volcanic fluid migration.

Since water coexists in liquid and vapour phases in LTF systems, their maximum temperature is buffered at the boiling point of water at the elevation of a certain fumarole (100°C at 0 m a.s.l.), limiting the upper-going dynamic of LTF thermal signals with respect to HTFs. On the other side LTFs are usually fed by hydrothermal circulation in porous systems, much more reactive to tectonic stress changes than HTFs, supplied by water vapour circulating in fractured media.

For the abovementioned reasons since the year 2005 the continuous monitoring of LTFs has been a part of the INGV surveillance program of Italian active volcanoes, with stations acquiring hourly temperature data of LTFs located at Vulcano, Stromboli, Etna and Vesuvio.

After more than 10 years of observations the huge amount of data acquired in the INGV-LTF network allows a retrospective analysis of this methodology, giving useful indications about successful applications, limits and perspectives of LTF temperature monitoring, that is the matter of this presentation.

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Rapid quantification of geomorphological changes at active volcanoes: strategy, techniques and results

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Keywords: Active volcanoes, Rapid geomorphological changes, Eruptive activity, Topographic maps, High-resol

Many active volcanoes worldwide are characterized by frequent and rapid morphostructural changes. Mt. Etna is among the world's most active volcanoes, displaying an almost continuous eruptive activity from the four summit craters. As such, its uppermost region is continuously changing, with new vents suddenly appearing and becoming wider and deeper, and cinder cones growing as a consequence of powerful explosive activity. This involves that the available maps of the summit zone become soon too old to represent its morphology and structural asset, and updated Digital Elevation Models are continuously required to run lava flow models for hazard estimation during effusive eruptions. It is thus of paramount importance to obtain precise and continuously updated topographic maps of the summit region, because these also allow us to quantify the eruptive products, and from these data we can obtain the output rate and evaluate the state of the volcano and its potential of future eruptions. In addition, being the flanks of Etna very populated and visited by thousands of tourists every year, to have available updated topographic maps becomes essential for both monitoring and civil defence.

Here we present new topographic maps of the Mt. Etna's summit area. One of the major problems to be addressed was to quickly obtain high resolution data on a very active volcano, and without excessive risk. In order to perform our job optimizing time, risk and costs, we have chosen to take numerous high-resolution photos, thermal images and footage from a helicopter. Then we processed this material obtaining a orthophotography of the target zone. The topographic data were then validated through LiDAR ground measures previously acquired in zones very close to the summit craters and not affected by morphological changes. The final result is represented by the construction of some thermal and topographic maps of the summit area of Etna, at various scales.

RST_{VOLC} : a satellite-based algorithm for volcanic thermal activity monitoring from space

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Keywords: Volcanoes, Satellite, RST_{VOLC}.

RST_{VOLC} (Marchese et al., 2011; Pergola et al., 2015) is an ad-hoc configuration of the Robust Satellite Techniques (RST) multi-temporal approach developed for volcanological applications using two local variation indices in combination to detect hot magmatic surfaces. The algorithm was tested processing infrared AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer) records. Afterwards, it was implemented on SEVIRI (Spinning Enhanced Visible and Infrared Imager) data allowing us to monitor short-lived events (thanks to the 15 minutes temporal coverage offered by the geostationary attitude) like the recent paroxysmal events of Mt. Etna (Italy). In this work, we present a set of RST_{VOLC} observations performed studying active volcanoes located in very different geographic areas. The potential of RST_{VOLC} in detecting subtle hot spots is assessed even for comparison with other state-of-art satellite methods. Moreover, the contribution offered by the algorithm in characterizing the different thermal phases of volcanoes is evaluated analyzing some recent eruptions of Etna, Stromboli (Italy), Eyjafjöll (Iceland) and Shinmoedake (Japan) volcanoes (e.g. Lacava et al., 2014). The work shows that RST_{VOLC} is capable of guaranteeing a high confidence level of detection in different observational conditions. In addition, it seems sensitive to thermal precursor signals of volcanic eruptions. RST_{VOLC} may then represent an important tool for the active survelliance of high-risk volcanic areas (e.g. Vesuvius; Campli Flegrei) from space, especially if integrated within an automated eary warning system aiming at providing timely and reliable alerts about new phases of thermal unrest.

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A perturbative approach for the modelling of short-term fluid-driven ground deformation episodes on volcanoes: the case of Campi Flegrei caldera (Italy)

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Keywords: Campi Flegrei caldera, geothermal system, perturbative fluid dynamics, volcano ground deformation

We developed a numerical time-dependent inverse method, which allows retrieving the flow rate of fluids injection in hydrothermal systems by using the observed ground deformation. The base assumption is that short-term ground uplift episodes (T<5years) depend on injection of volcanic fluids into the hydrothermal system. We demonstrate that under general hypotheses, a perturbative approximation, around a steady state of a thermo-fluid dynamics system, allows using a linear approach based on numerical Green's function. It linearly connects the evolution of the deformation field to the injected fluid rate. The thermo-fluid dynamics modeling (Tough2 code) was applied to a 3D permeability and porosity model of Campi Flegrei caldera (CFc), Southern Italy, and used to calculate both the steady state and the numerical empirical temporal Green's function (netGf). We modeled the ground deformation, estimated by the satellite InSAR technique, by computing the elastic response to the injection at depth of pressurized hot volcanic fluids (CO_2/H_2O mixture). This was done by taking into account both the poroelastic and the thermoelastic strain. We calculated the deformation in a 3D tomographic elastic model of the CFc through COMSOL-Multiphysics, and regarded the pressure as acting as isotropic stress in the 3D mesh. The thermo-elastic strain was calculated by the thermic expansion coefficient. We estimated a NE-SW elongated source (2 km long and placed at 2400 m depth in the middle of the caldera) connected and fixed in the space. We used this fracture as a source to construct our netGf, the deformation response of the surface to a single short injection in the source cells. We applied the method to the years 1987-2013 A.D., and we found a good agreement between the measured and the estimated temporal deformation patterns. We conclude that, when accompanied by degassing phenomenon, such approach can give a physical representation of the source nature for the short-term ground uplift episodes at CFc. The method allows estimating the amount of hot volcanic fluids, correlating these to the early deformation due to the poroelastic effect. The temporal resolution depends on the duration of the used numerical Green's function. This, together with the availability, almost in real time, of InSAR data, represents a promising tool to estimate volcanic variation of the system state as risk mitigation.

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Role of Mechanical Erosion in Controlling the Effusion Rate of Basaltic Eruptions

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Keywords: Lava Flow, Effusive Eruptions, Volcanology, Effusion Rate.

In many basaltic eruptions, observations show that the effusion rate of magma has a typical dependence on time: the effusion rate curves show first a period of increasing and later a decreasing phase by a maximum value. We present a model to explain this behavior by the emptying of a magma chamber through a vertical cylindrical conduit with elliptical cross section, coupled with the its widening due to mechanical erosion, produced by the magma flow. The model describes the effects of mechanical erosion on the conduit width, as a function of the volcanic conduit shape and dimension, the overpressure in the magmatic chamber, the volume flow rate, and the cumulative volume of emitted lava. The model shows that the erosion rate is in the order of field observations (Wadge, 1981). Furthermore, the model reproduces the effusion rate on time found by Vicari et al. (2011) for Mt. Etna, in particular the maximum values of effusion rate, eruption durations and emitted lava volumes. The model shows that the value of the erosion rate per unit traction has a great influence on the lava flow in the conduit, whereas the radius of magna chamber and viscosity has a smaller effect: in particular, as expected the eruption duration increases if erosion rate decreases.

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DInSAR deformation analysis and modelling of megathrust earthquakes: examples from Gorkha (Nepal) and Illapel (Chile) events

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Keywords: Earthquakes, DInSAR measurements, source modelling.

The analysis of surface deformation associated with a seismic event (i.e., permanent deformation associated with earthquakes) is extremely useful for a better understanding of the seismic source, especially when the stress release occurs slowly. In this context the use of differential interferometry DInSAR technique plays a fundamental role in the study and analysis of coseismic deformation both to small and large observation scale.

Here, we present two recent cases on 1) how getting information on surface displacement related to megathrust earthquakes from satellite data and 2) the strategies to model the causative faults: the Mw 7.8 Gorkha (Nepal) and the Illapel (Chile) earthquakes occurring on 25 April 2015 and 16 September 2015, respectively.

The Gorkha earthquake had its epicenter localized at about 82 km NW of the Kathmandu city and the hypocenter at a depth of approximately 15 km. We model the causative fault, through a 2D Finite Element (FE) numerical modelling, by jointly exploiting surface deformation retrieved by the DInSAR measurements collected through the Sentinel 1-A (S1A) and ALOS satellites and the available geological, structural and seismological information. Our inversion suggests that the maximum slip is confined at a depth of 7–15 km along the Main Himalayan Thrust (MHT) and occurred in the area about 30 km northern of Kathmandu with a maximum value of about 7.5 m. The main-shock ruptured the deep part of the seismogenic zone of MHT, with lower displacement values along the splay faults in the south region. In addition, we find more than 3 m of displacement in correspondence to the shallow portion of the Main Central Thrust (MCT) to the north.

The Illapel earthquake occurred off the coast of Central Chile in Coquimbo area at a depth of 25 km. The epicenter, located 46 km west of Illapel city, shook buildings in the capital city of Santiago and generated a tsunami that caused flooding in some coastal areas. We perform a coseismic slip fault modeling based on multi-orbit S1A data, by using an analytical and FE approach. The analytical inversion showed that most slip occurs northwest of the epicenter, with a maximum located in the shallowest 20 km. Then, we use the FE modelling to simulate the slip along the slab curvature, the von Mises stress distribution, and the principal stress axes orientation. The von Mises stress distribution shows a close similarity to the depth distribution of the aftershock hypocenters. Likewise, the maximum principal stress orientation highlights a compressive regime in correspondence of the deeper portion of the slab and an extensional regime at its shallower segment; these findings are supported by seismological data.

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Long Term Analysis of RST-TIR Satellite Observations in Greece, Italy, Turkey and Japan: a possible contribute to a multi-parametric system for the time-Dependent Seismic Hazard Assessment (t-DASH)

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Keywords: Robust Satellite Techniques (RST), seismic hazard forecast, seismic precursors, earthquakes, Greece.

No one single measurable parameter or observational methodology has demonstrated, until now, to be sufficiently reliable and effective for the implementation of an operational earthquake prediction system. However the combined use of independent observations, together with suitable data analysis methods, are expected to strongly improve quality of seismic hazard estimation in the short (weeks) and very short (days) term. Before the integration an independent assessment of each candidate precursor should be performed in order to establish the strength of its (possible) correlation with earthquake occurrence and its actual informative contribute in a multi-parametric OEF (Operational Earthquake Forecast) scheme.

Since 2001, the general change detention approach, named Robust Satellite Technique (RST), has been applied to explore the fluctuations of Earth's thermally emitted radiation - observed by satellite sensors operating in the Thermal InfraRed (TIR) spectral range - in possible relationship with the preparation phases of major earthquakes. Thanks to its intrinsic exportability it was used to study the preparation phases of earthquakes within a wide range of magnitude (from 4.0 to 7.9) in different geo-tectonic contexts (compressive, extensional and transcurrent) in four different continents. It showed good ability to isolate anomalous space-time TIR transients possibly associated to seismic activity, from the normal variability of TIR signal due to other causes (e.g. meteorological). In this paper the space-time correlation between TIR anomalies, identified by the RST methodology, and earthquakes (with $M \geq 4$) is evaluated by retrospective long-term analyses carried out in four different seismic areas of the world, like:

- Greece, using MSG/SEVIRI TIR observation since May 2004 up to December 2013 (10 years);
- Italy, using MSG/SEVIRI TIR observation since May 2004 up to December 2014 (11 years);
- Japan, using MTSAT-1R and MTSAT-2 TIR observation since June 2005 up to December 2015 (11 years);
- Turkey, using MSG/SEVIRI TIR observation since May 2004 up to October 2015 (12 years).

More than 10.000 satellite images (for more than 10 billions of records) where analyzed in order to identify, by using the RST approach, Significant TIR Anomalies (STAs). Prescriptions on STA's relative intensity - measured by the RETIRA (Robust Estimator of TIR Anomalies) index - and space-time persistence, were used to identify Significant Sequences of TIR Anomalies (SSTAs). A correlation analysis among the appearance of SSTAs and time, location and magnitude of earthquakes, was performed by applying predefined space-temporal and magnitude constraints. Preliminary results highlight that, depending on the considered geographic region, the occurrence of SSTAs falling out of the pre-fixed space-time correlation window range between 7% (Greece) and 39% (Italy). Molchan error diagram analysis gives a clear indication of non-casualty of such a result with a probability gain (compared with a random guess) ranging from 1,5 up to 3,5. Such a result confirm a positive informative contribution that the use of SSTAs could give in the framework of a multi-parametric system for a time-Dependent Assessment of Seismic Hazard (t-DASH).

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Low cost UAV system as support to volcanic hazard assessment

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Keywords: UAV, volcano, DEM, hazard.

The term UAV (Unmanned Aerial Vehicles) refers to an aircraft without an on-board human pilot. UAVs can be remotely controlled by a pilot on the ground or can fly autonomously relying on pre-programmed flight plans or more complex dynamic automation systems. UAVs have seen unprecedented levels of growth in military and civilian application domains. In the last five years only, the total quantity of UAVs has more than doubled, and so is the quantity of producers and developers. The increased demand for UAVs is typically attributed to the low manufacturing and operational costs, flexibility of the platforms to accommodate the consumer's particular needs and the elimination of the risk to pilots' lives in difficult missions. The continuous trend in the miniaturization of electronics enables the production of smaller UAVs while simultaneously equipping them with cameras and other sensors to support aerial geo-data collection. With low cost, small, and lightweight integrated GNSS and inertial navigation systems, UAVs can be navigated with decimeter accuracy and the acquired orientation parameters can reduce the number of ground control points needed for post-processing. For this reasons, they are actually considered a suitable and cheaper alternative solution compared to other mapping systems. With this in mind, a study was performed to illustrate the potential applications of UAVs as support to volcanic hazard assessment. For example, one basic requirement to perform realistic numerical simulations of lava flow path during an eruption is the availability of an updated DEM (Digital Elevation Model); but other potential applications deriving from reiteration of surveys include also volume estimation; this mean to have an average value of flow rate to drive numerical simulation (Vicari et al., 2009). From 2015 at INGV-OE are available two quadcopters DJI Phantom 3 Professional equipped with a 12 Mpx camera and 1 octacopter based on the Foxtech Kraken 130 frame, a maximum payload of 8 kg and a Sony Alpha 6000 24 Mpx camera. A semi-automatic chain for acquisition and elaboration of data has been developed and the first applications should be shown in both volcanic and not environment.

Vicari A., Ciraudo A., Del Negro C., Herault A. & Fortuna L. 2009. Lava flow simulations using discharge rates from thermal infrared satellite imagery during the 2006 Etna eruption. Natural hazard, 50, 339-550.

SESSION S25

Geological safety of built and urban areas

CONVENERS AND CHAIRPERSONS

Francesco Maria Guadagno (Università del Sannio)
Carlo Esposito (Università di Roma La Sapienza)
Claudia Meisina (Università di Pavia)
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Stability problems and consolidation works in the ancient town of Matera

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Keywords: Rock slope stability, Natural Hazard, urbanized environment, cultural heritage.

The ancient historical centre of Matera in Southern Italy is called "Sassi" and it is a prodigious example of the use and modification of the natural environment by human activity and of how the urban development of some human settlements is strictly related to the geological environment that condition the structural and architectural choice. "Sassi" occupy the upper part of the right hand side of the narrow deep gorge of Gravina di Matera torrent where Quaternary sandstone outcrops, locally called "tuffs" overlying Mesozoic limestone. It is one of the most singular examples of rupestrian habitat all over the world, so that it has been included in UNESCO World Human Heritage. This site has been inhabited since Palaeolithic age to few years ago. The human presence in this area was favoured by the morphological characteristics and by the geolithological and petrographic composition of the sandstone easy to be dug out and to be carved.

In several zones of the ancient town there are severe stability problems and risk of large and small rock-fall that may create problems for safety, especially in consideration of the high touristic presence in this area. The work illustrate the study developed to evaluate the main possible instability phenomena and the level of landslide risk in two areas particularly relevant from the touristic point of view: Idris rocky block and Casalnuovo cliff. A detailed study of discontinuities features allowed to define the potential instable blocks and to design consolidation works to improve the level of safety. Consolidation works were planned and developed on the base of this detailed study with the purpose of improving safety, avoiding to create problems to environment, preventing the visive impact on these heritage areas.

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Liquefaction potential in fine-grained sedimentation environment: Fucino lacustrine basin, central Italy

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Keywords: Liquefaction susceptibility, fine grained soils, lacustrine environment.

We analysed the liquefaction susceptibility of an area located in the northern side of the Fucino lacustrine basin in central Italy (Pozzone area). The Fucino was struck in 1915 by a M7.0 earthquake, which produced widespread coseismic surface effects interpreted as liquefaction-related. In the Pozzone area the interpretation of the described phenomena is not straightforward. In fact, though several phenomena described after the 1915 earthquake can easily be interpreted as liquefaction (fracturing with water and sand venting, sand volcanoes), for other phenomena observed in the Pozzone area the interpretation is doubtful (ground deformation, water-level variations, water emissions, turbidity in natural lakes). Previous studies suggest that in Pozzone the earthquake might have triggered mechanisms of deep piping (and surface sinkholes). They are significantly different from the shallow-origin mechanisms (<15-20 m depths) responsible for liquefaction in strict sense. Moreover the site is characterized by prevailing fine-grained sediments which are not the typical liquefiable soils.

Detailed investigations (continuous-coring well, CPTu, SDMT, SPT, laboratory tests) were realized in order to remove uncertainties and provide insights for the liquefaction potential in a lacustrine environment, dominated by fine-grained sedimentation.

The first 18.5 m stratigraphy is dominated by fine-grained sediments, with four packages of coarser sediments formed by interlayered sand, silty sand and sandy silt. These packages, interpreted as frontal lobes of an alluvial fan system within the lacustrine succession, are highly susceptible to liquefaction. We found evidence of a paleo-liquefaction at 2.1-2.3 m depth that together with the geotechnical analyses pointed out that the site is liquefiable for 1915-like earthquakes.

Though we found a broad agreement among CPTu, DMT and shear wave velocity "simplified procedures" in detecting the liquefaction potential of silty sand-to-sandy silt layers, our results suggest that the use and comparison of different in situ techniques are highly recommended. In these geologic environments, where no obvious liquefiable layers can be detected, only in situ characterization and laboratory analyses together with detailed stratigraphic reconstructions can support professional geologists to recognize those sites susceptible to liquefaction.

CLoud plAtform and smart underground imaging for natural Risk Assessment in urban areas: the Clara project.

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Keywords: urban areas, infrastructures, sensor synergy, tomography.

The CLARA project was funded by Italian Ministry of Education, University and Research in the frame of a national call on the topic "Smart Cities & Communities – Thematic Priority: Homeland Security". The project is promoted by a large public-private partnership with the participation of CNR, OGS, University of Ferrara, Roma-LaSapienza, Enna and Catania, leading national private companies and SME consortia.

The project proposes a systemic approach for the characterisation of the main physical and geometrical properties of subsurface in urban areas based on the full integration of geophysical exploration technologies (seismic tomography, microwave tomography, resistivity tomography, etc..), advanced sensors (fiber optic sensors, low-cost accelerometers, etc..) and ICT architecture (web-services, web-sensors, etc..) for the development of an open, scalable and interoperable platform for the sharing, visualization and management of geospatial data.

To-date, there is a growing demand of innovative products for the management of activities to be implemented in the most superficial portion of the subsoil and to study the soil-structure dynamical interactions in urban settings (Showstack and reference therein, 2014). The mitigation of the effects of natural disasters (earthquakes, landslides, etc.), the realization and monitoring of strategic infrastructures (energy pipelines, mobility network, etc) and the exploitation of the natural resources (groundwater, geothermal fluids, etc..) are strategic priorities in any approach of urban planning and strongly require a complete geological/geophysical characterization of subsurface.

This project responds to this demand by integrating the latest enabling technologies (active and passive; direct and indirect; multi-sources and multi-resolution) for the geophysical exploration of the subsoil and the dynamic characterization of structure/infrastructures. The proposed system is based on non-invasive technologies suitable for 2D and 3D imaging of the subsurface in an urban environment, in which there is generally an intrinsic difficulty to work with direct surveys (surveys and invasive drilling).

The project identifies three main urban case-studies: the city of Ferrara; the Province of Enna and the city of Matera. The latter, with its historical center of the Sassi UNESCO World Heritage Site, is interested in broadening the knowledge of the subsurface exposed to a series of hydrogeological instability phenomena. Recently, Matera has been appointed as European Capital of Culture 2019. In this work the preliminary results of a field geophysical campaign carried out in Matera are presented and discussed.

Showstack R. Scientists Call for a Renewed Emphasis on Urban Geology. EOS Earth & Space Science News (November, 2014).

Interactions between relict landslides and built environment: hazard investigations and monitoring at Mendatica (western Liguria, Italy)

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Keywords: Relict landslides, Deep-seated landslides, Landslide hazard, Displacements monitoring, Flysch rock.

The Mendatica relict landslide is one of the most representative examples of the impact of natural hazard on the built environment in the western sector of the Liguria region (north-western Italy). Over the wide landslide body it is located the small settlement of Mendatica where witnesses of damage suffered by buildings, main roads as well as water pipelines are extensively documented since 1970 (Federici et al., 2007). The Mendatica landslide is a deep-seated mass movement affecting a wide slope segment of the Western Ligurian Alps and characterized by the superimposition of two highly heterogeneous flysch rock masses with different mechanical behaviour (Pepe et al., 2015). As most of the relict landslides and slope deformations appearing in Liguria (e.g.: Carobene & Cevasco, 2011; Cevasco & De Vita, 2015), also the Mendatica landslide was probably activated under past morphological/climatic conditions. It shows a complex evolution due to composite mechanisms, rock and soil heterogeneity and a difficult hydrogeological setting. Although the movements no longer involve the whole landslide body, residual displacements still affect some sectors of the accumulation zone with different degrees of activity. In the last decades, the landslide reactivations have frequently and significantly conditioned the safety of the local inhabitants. In March 2013, an abrupt reactivation of the landslide accumulation gave rise to homeless and evacuated people. In the last twenty years several surface and subsurface investigations and monitoring activities were performed with the purpose of designing risk mitigation measures: (i) geological/geomorphological surveys, (ii) boreholes, (iii) in situ and laboratory testing, (iv) seismic surveys, (v) inclinometric and piezometric monitoring (since December 2006), (vi) interferometric monitoring (PSInSAR technique), and (vii) crack monitoring on buildings. Despite various inclinometers broken down due to landslide activity between 2011 and 2013, some boreholes monitoring are still ongoing and new investigations have been undertaken since 2013. As accelerations of the unstable landslide body were observed after intense or prolonged rainfall, groundwater controlling measures were adopted since 2015 and a rain gauge was installed to improve the existing monitoring system. In this study, a great deals of geological/geotechnical and monitoring data were collected in order to investigate the geological setting of the Mendatica landslide and its kinematic. The preliminary results have allowed to identify the features of the landslide accumulation, which is still active down to a maximum depth of 28 m with recorded velocities up to 8 cm yr^{-1}, and the most hazardous areas. Future activities focusing on monitoring of rainfall, groundwater and landslide displacements could be very useful in testing the effectiveness of the adopted measures and therefore in achieving a detailed safety evaluation of the urbanized area.

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Federici P.R., Capitani M., Chelli A., Del Seppia N. & Serani A. 2007. Atlante dei centri abitati instabili della Liguria. vol. IV - Provincia di Imperia. C.N.R. G.N.D.C.I, Regione Liguria, Università degli Studi di Pisa, Tipografia Nuova Ata, Genova.

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Ground motion modeling for the April 6, 2009 (M_W=6.3) earthquake at L'Aquila district

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Keywords: April 6, 2009 (Mw=6.3) earthquake, Vs models, ground motion modeling.

A M_W 6.3 earthquake (main shock) struck on 6 April 2009, at 01.32 GMT, the Abruzzo region (central Italy). The L'Aquila town and several villages located nearby, suffered heavy damages and 308 people lost their lives.

The epicentral area of the main shock corresponded to the Aterno river valley, a tectonic depression where a lacustrine deposition occurred in the Pleistocene. It is a complex geological structure with a carbonate basement outcropping along the valley flanks and elsewhere buried below alluvial and lacustrine deposits with variable thickness. At L'Aquila, the surface geology is even more complicated by the presence of breccias (so called megabreccias), consisting of limestone clasts in a marly matrix.

The mainshock was recorded at the historical centre of L'Aquila while some aftershocks were recorded at Poggio Picenze (INGV-RAIS and RAN networks), located ~12 km SE of L'Aquila, in the southern sector of the Aterno river valley. Two-dimensional sections have been drawn along the alignment epicentre - recording stations based on available geological studies and geophysical information mostly regarding active seismic experiments in correspondence of very shallow drillings. The estimation of ground motion needs the knowledge of the physical properties of rocks at depths greater than hypocenter. At this aim, we have analyzed the earthquake recordings ($M \geq 3.0$) in the April-November 2009 time window. Group velocity data of the fundamental-mode Rayleigh waves have been defined with frequency-time analysis and inverted to get shear wave (V_S) velocity models with depth (up to ~2 km depth). At greater depth, the regional earth model has been assumed.

Ground motion for the main shock has been computed along 2-D cross-sections with a hybrid method (modal summation plus finite differences). At L'Aquila historical centre (I= IX-X MCS) such estimation has been validated with recordings. Instead, at Poggio Picenze (I=VIII MCS), the main shock has been simulated after the validation of ground motion computed for the greatest recorded aftershock (M_W=4.3).

At the historical centre of L'Aquila, a general agreement has been obtained between synthetic and observed response spectra through parametric studies of V_S velocities of the shallowest lithotypes. It results that the megabreccias covering on lacustrine soils, is responsible of spectral amplifications along the vertical (2-7) and horizontal components (2-3) at a wide frequency range (0.6-7 Hz).

At Poggio Picenze, spectral amplifications of 5-6 have been estimated at 3–4 Hz for the vertical component and up to 2–3 at 2–6 Hz for the radial and transverse components. Maximum ground accelerations have been computed in the horizontal plane, along the transverse component (around 0.4 g).

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The evaluation of the security of the built area behind the *Embankment* structures in the final part of the Biferno river (Molise Region)

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Keywords: Embankment structures, risk management.

In the past, the "physical space use" by man was so limited, that only in rare cases it was necessary to protect the territory against flooding, reducing the risk. Nowadays the social and economic development and the extension of the populated territory have produced an increase in the risk situations with an always growing request of protection and/or mitigation measures.

The most common works used by man to protect himself against floods are embankments.

It is a strengthened rule to evaluate the safety conditions of the ambiance behind the embanked structures through an exclusively "hydraulic" approach: hypothesizing on the perfect efficiency and integrity of these structures also against surmounting phenomena, the territories behind infrastructures which are able to contain the project overflow are considered "safe", while the territories behind infrastructures which are not able to contain the overflow are considered "dangerous". The several registered experiences, as well as recent works have highlighted both how, during floods, the "ex ante" forecasts, evaluated with an hydraulic approach, appear to be underestimated in comparison to those actually registered, when embanking wreckages occur (Cuculo et al. 2013), and how the risk conditions in the territories on the back of vulnerable embankment structures are highly increased and they are not always easy to define except through "fuzzy methodologies" (Bogardi 2007).

This paper illustrates a method to evaluate the safety of the built area behind handcrafted structures, also taking into account an index of vulnerability of rapid assessment (Cuculo et al. 2014, 2015), which was used in the elaboration of the Alluvial Risk Management Plan, expected by the 2007/60/CE Directive, in the Biferno river basin, which lies in the Southern Apennine District.

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Geotechnical characterization of secondary raw materials for road constructions

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Keywords: geotechnical characterization, secondary raw materials, road.

Quarrying ornamental stones produce large amounts of waste materials. In Sardinia, about 200.000.000 m3 of scrap materials, corresponding to the 40% of the total volume of stone material extracted, is accumulates as waste material near the extraction sites, occupying more space than the quarrying operation themselves (RAS, 2007). These huge volumes pose serious environmental and landscape impact, particularly in touristic areas (i.e. Gallura region). According to the Green Public Procurement (GPP) approach, the Regional government of Sardinia enacted the "Guidelines for the application of GPP for works contracts: using of quarries scraps of marble and granite in road constructions" (2012). In order to investigate the possible use of stone waste materials in road constructions, samples from three granite waste dumps, traded as Rosa Beta (RB), Ghiandone (G) and Grigio Malaga (GM), were collected in January 2016 and characterized taking into account the 5205/2005 circular, which defines the technical and performance criteria that recycled materials should possess. The prequalification analysis of materials comprised the petrographic descriptions (EN 932-2), the determination of particle size distribution (EN933-1), the determination of the consistency (Atterberg - CNR UNI 10014), the particle shape index (EN 933-4), the flakiness index (EN 933-3), the sand equivalent test (UNI EN 933–8), the determination of granule volumic mass and water absorption (UNI EN 1097-2), the Los Angeles Test (CNR BU 74/1973), the modified Proctor test (CNR BU 69/1973), the bearing capacity using the CBR test (CNR UNI 10009) and the leaching test (UNI 10802/2004). Preliminary results highlight that the materials collected in the study areas have technical characteristics consistent to their use in constructing roads. However, the degree of alteration of the materials affects their possible use. Ghiandone showed the lowest performance characteristics due to a pervasive microfracture system, which could be responsible for a water absorption index about three times higher than RB and GM and for a Los Angeles quality index of 50%, much higher comparing the value of 18% for RB and 20 for GM. These characteristics make it not evaluable for subbase pavement. Other critical issue emerging from this preliminary assessment regards that the highest volumes of wastes are represented by blocks several cubic meters wide. The reuse of these blocks in road constructions would require considerable investments in crushing plants. Life cycle assessment methods were proposed to manage scrap stones (Coni et al., 2002), but their implementation is still far to be applied. RAS (Regione Autonoma della Sardegna), 2007. Piano Regionale delle Attività Estrattive, Regione Autonoma della Sardegna, Cagliari.

Coni M., Annunziata F. & Luciano A. 2002. Impiego dei residui di cava nelle infrastrutture stradali della regione Sardegna, Strade e Autostrade, 1.

Tectonic drives related to slope instability phenomena in Salandra, Basilicata, south Italy

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Keywords: landslide, natural hazard, tectonics, urbanized area.

Salandra is a town located on the top of a hill, which is oriented according to the Apennine direction, i.e. North-West to South-East, geologically characterized by the typical sequence of layers of the hills in the Bradanic foredeep domain. The town is located close to the passage between the foredeep to chain domain, therefore the sedimentary sequence was conditioned by the effects of the uplift of the Apennine chain. These strongly disturbed the clay masses, creating large blocks and conditioning the local geological structures (Galeandro et al., 2013; Doglioni et al., 2015). The stream network is conditioned by tectonic-gravitative ruptures, rather than by erosion phenomena. The erosion secondarily affected these tectonic ruptures.

The large block, on the top of which there is Salandra, it tilted towards East, due to the effects of the Apennines, thus causing an asymmetry of slopes, which are very steep towards the Apennine (West) and lower towards the foredeep domain (East).

On this premise, the western side of the town is very steep, and it is not involved by deep gravitative phenomena, while shallow landslides occur, whereas these are channelized into the failures of the clay block. These originated during the tectonic uplift, and became preferential flow paths of water, thus causing an upward erosion. These erosion phenomena of the bottoms of these channels cause clay debris flows, fed by the slides of materials on the sides of the channels. The erosion of these valleys involves the toes of the slides, causing rotational landslides of medium depths with quick cinematics, which involves the top of the slopes, thus withdrawing the upper bound of these landslides. These shallow landslides can cause severe consequences on that part of Salandra located at the top of the involved sides.

The western side of the town is characterized by deep seated landslides, with slow cinematics, fostered by the landslide prone configuration, due to the tectonic tilt of the block on which there is Salandra.

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Doglioni A., Galeandro A., Guerricchio A. & Simeone V. 2015. Tectonic stress as possible co-predisposing factors for landslides along the central Adriatic coast of Italy Engineering Geology for Society and Territory – Volume 2 Landslide processes; doi: 10.1007/978-3-319-09057-3_42.

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Seismic microzonation of Castelnuovo (L'Aquila): investigations to refine the subsoil model for the amplification effect evaluation

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Keywords: seismic microzonation, subsoil model, Quaternary Geology, microtremor.

Castelnuovo village, located in the Paganica-S. Demetrio-Castelnuovo Basin (PSCB), suffered heavily the April 6 2009 - Mw 6.1 L'Aquila earthquake as evidenced by the catastrophic collapse of shallow caves and the overlaying buildings. The PSCB complex graben is filled up by mostly lacustrine calcareous silts (San Nicandro Fm.) and fluvio-deltaic conglomerates and sands, giving way to transitional deposits and carbonate slope breccias towards the lake margins, belonging to the late Piacenzian-Gelasian San Demetrio Synthem (Nocentini, 2016; Spadi et al., 2015). These sediments represent the first infilling stage of the basin, laying directly upon the Meso-Cenozoic substratum. Geomorphologically, the PSCB is arranged in en échelon small basins divided by elongated ridges. Castelnuovo is placed on one of these small ridges, which is N-S trending and 60 m higher than the present valley floor. Castelnuovo buildings intense downfall can be due to the stratigraphic amplification (i.e. San Nicandro silt as soft sediment laying onto limestone as stiff bedrock) and the widespread collapse of shallow caves located beneath the buildings. Therefore, the USRC department started a remarkable investigations plan to refine the subsoil model to estimate the amplification effect through fine-scale geological survey, boreholes, down-hole tests and microtremor measurements. Castelnuovo area, as attained by geological survey, is characterised by Gilbert-type delta gravels and sands (Valle Orsa Fm.) on top ridge, passing downward to San Nicandro silt, here with a thickness of about 50-100 m, laying upon the carbonate substratum. Several normal faults located at the boundary of Castelnuovo ridge displace the Plio-Quaternary formations and the underlaying Meso-Cenozoic bedrock. A deep borehole executed at the bottom of Castelnuovo ridge reached the seismic bedrock at 49 m bgl. In the Castelnuovo ridge nine 30m-depth continuous-core boreholes were drilled into the San Nicandro silt; for three of them, down-hole tests were carried out showing a Vs value about 300 m/s. The microtremor measurements show f0 in the range of 1.25 and 2.7 Hz. Using the f0 vs depth empirical correlation obtained for the Western L'Aquila Basin, the seismic bedrock surface below the Castelnuovo area has been more precisely reconstructed. The subsoil model has been summarised by geological cross-sections longitudinal and transversal to the Castelnuovo ridge, which will be used for the 1D and 2D numerical simulations.

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The cave systems of Castelnuovo (L'Aquila): multidisciplinary investigations for ground consolidation

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Keywords: seismic microzonation, subsoil model, caves network.

Castelnuovo is placed in the Plio-Quaternary Paganica-S. Demetrio-Castelnuovo Basin (PSCB) complex graben (Giaccio et al., 2012; Nocentini, 2016), corresponding to the NW-SE oriented middle Aterno R. Valley. At the local scale, Castelnuovo is placed on a small ridge, which is trending WNW-ESE and is 60 m-high. It is characterised by alluvial sand and gravels (Valle Orsa Fm.) on top ridge, passing downward to the 50 m-thick lacustrine San Nicandro silt laying upon the Meso-Cenozoic carbonate substratum. Castelnuovo urban peculiarity is represented by many shallow cave systems inside the San Nicandro silt, which are just located below the buildings. They are probably of anthropic origin, forming a poorly known network probably arranged in more overlying levels. Castelnuovo was stricken hardly (macroseismic intensity grade: IX-X), as many villages of the Aterno R. Valley, by the April 6 2009 - Mw 6.1 L'Aquila earthquake as showed by the catastrophic collapse of these caves, which involved also the overlying buildings. The collapsed caves have to be consolidated by means of specific grout or recycled aggregate filling before rebuilding the Castelnuovo village. Therefore, within this goal the USRC department started up a subsoil investigations plan to reconstruct the caves network being pivotal for the subsequent consolidation activity. The caves investigation plan was organised in the following steps: (i) caves information from previous reports; (ii) 1700 m-long ERT linear arrays were performed; (iii) after the ERT interpretation, 136 shallow destructive drilling boreholes were carried out. The boreholes campaign allowed to find 15 caves, whose three never known before, while previous data evidenced at least 67 caves. All the caves, which are approximately 25-30 m-long and 2-6 mhigh, are bored into the San Nicandro silt and are located 2-10 m below ground level. Sometimes, in the first meters from the entrance, the caves show consolidation works as simple retaining brick walls. Briefly, integrating previous data (Gruppo di Lavoro MS–AQ, 2010), the ERT arrays interpretation, the boreholes logs and the surface geology and speleo investigations has been possible to identify the caves network, basic for planning the caves consolidation activities.

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Landslides and flash floods induced by the 22 November 2011 storm, north-eastern Sicily

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Keywords: Rainfall, flood, landslide, Sicily.

Sicily has been hit recently by intense storms, which caused floods and landslides in many places. Particularly interested by recent intense storms has been the northeast sector, where a high and narrow ridge, the Peloritani mountains, extends between the Ionian and Tyrrhenian seas. After the event of 1 October 2009 of the Ionian side, on 22 November 2011 another catastrophic event occurred along the Tyrrhenian side, causing three deaths in Saponara village.

The storm was connected to an anomalous barometric condition between the northern side (Tyrrhenian basin) and south-eastern side (Ionian sea) of the Peloritani Mountains, inducing high speed Sirocco winds. These winds generally cause intense rainfall on the Ionian side of the Peloritani mountains, were the highest accumulated rainfall were expected the day before the storm. But, due to the very high intensity of winds during the 22 November 2011 towards the North, the rainfall accumulated mainly on the other side of the Peloritani water divide, causing unexpected landslides and flash floods along the Tyrrhenian side. Besides, few hours later the storm reached the southern Calabria, inducing further landsides and flash floods; a train derailed near Lamezia Terme, fortunately without further deaths.

The storm induced thousands of shallow landslides in two wide areas of the Peloritani mountains, one located in the middle catchment of the Saponara torrent, and the other across the catchments of Mela and Longano. Huge alluvial phenomena occurred in the urban area of Barcellona Pozzo di Gotto and Milazzo. The same areas were hit by flash-floods just one or few years before (on 11 December 2008 and 2 November 2010), and also last year (10 October 2015).

The causes of these hydrological catastrophic phenomena are connected with (i) the unfavorable urban conditions and (ii) the increasing of the frequency of occurrence of these storms in the autumn season in this area.

Both the above aspects will be described in this study. The accumulated rainfall of 22 November 2011 has been estimated by rain gauges available, supplemented by satellite data and considering the landslides distribution in the field. The maximum intensity was recorded in Castroreale, just above Barcellona Pozzo di Gotto, where more than 350 mm of rainfall were recorded during the morning of 22 November 2011 (between 6:00 and 15:00), with peak of 72.5 mm between 08:00 and 09:00. The hourly maxima never were recorded before.

The effects in the field have been amplified by an erroneous urbanization of the area, especially in the Milazzo plain where the local drainage network appear completely destroyed.

Seismic Response by GIS modelling in an urban area: prediction, accuracy and design utility

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Keywords: GIS modelling, SiSeRHMap computer methodology, Benevento, southern Italy.

GIS modelling is developed considering a layering parameterized architecture acting to reproduce the simplified subsoil models. Recently, the introduction of SiSeRHMap computer methodology (Grelle et al., 2016), which is based on a multi-phase hybrid model, permits to define multispectral acceleration seismic response maps and also maps of build-design spectra parameters using the above mentioned simplified layered structure. In a sector of the urban area of Benevento, Capodimonte district, the application of the SiSeRHMap methodology is performed trying to consider the epistemic uncertainties regarding the subsoil geometry and parameterization due to punctual data distribution of shear wave-thickness profiles and the stiffness variability of the lithology. A statistic approach and a Proximity Index is implemented in the code in order to take into account the uncertainties in the prediction. In addition, some specific aspects came from the use of the propose methodology in pre-existing-building area. These aspects deal with the likely use of over-layered analysis with geo-referenced multispectral data-maps produced by the introduced GIS-methodology and the vulnerability maps of building structure also considering their period of vibration.

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Natural hazard affecting the ancient town of Mileto (Southern Italy)

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Keywords: natural hazard, geological safety, deep seated landslide, urban area.

The ancient town of Mileto was the capital of Calabria-Sicily during the Norman domination of Ruggero I the Norman (1031-1101). It was several times destroyed by earthquakes during last centuries and rebuilt after 1638 earthquake (Vivenzio, 1788) uphill as new town of Mileto, partially destroyed by 1908 earthquake too. The work proposes an interpretation of local morphology and stream network paths in the area of the towns of Paravati and Ancient Mileto several times destroyed by earthquakes during the last centuries, as consequences of giant deep-seated landslides affecting the right side of the valley. The presence of giant landslides disarticulates the Tertiary and Quaternary deposits, favouring the amplification of earthquake effects. The identification of these huge landslides structures as that recognized elsewhere (Galeandro et. al., 2013; Doglioni et al. 2015; Guerricchio et al. 2012; Guerricchio & Simeone, 2012) also by innovative approaches (Doglioni et al. 2014), allows to better understand the complex geological structures of this area and to understand why this morphological strategic site is particularly vulnerable in terms of seismic hazard.

The western side of river Mesima valley in Calabria (Southern Italy) is characterized by several cyclopic giant deep seated landslides, related to the uplift and the opening of the homonymous tectonic trough, between Mount Poro and Serre mountain range.

The eastern side of the valley is constituted by a thick sequence of marine and continental deposits, ranging between Miocene to Pleistocene, sliding down the trough in multiple cyclopic deep seated landslides. The presence of these large phenomena is recognizable by several geomorphic evidences: the asymmetry of Mesima trough, the path of river Mesima, high scarp on the west side of the trough. Quaternary, continental deposits on the western side of the valley are displaced and disarticulated at various altitudes, while on the eastern side they remain more or less intact at the same altitude in which they originally made up.

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Integrated platform of risk analysis

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Keywords: risk management tools, components of the territory, acceptable risk, resilience.

Risk management is based on a good knowledge of hazards and element at risk; however, in many countries, information on exposed elements are often insufficient or not made available, and decision-makers do not have tools to understand their territory, the constraints affecting it, and so take right decisions to reduce risk. Policymakers need to be able to have information and indicators to develop their national strategies and define operational action plans in close coopération with populations. Alcyon has developed a set of tools, within a global platform for assessing the hazards and risks, to characterize dynamically all components territory, and finally to define, also in a dynamic way indicators for decisions-makers. This platform mainly comprises two complementary tools: Argus and Atlas. Argus allows authorities to have a global view of the level of risk on the basis of hazard indicators, and vulnerability; a specific module on capacity assessment to identify gaps and to identify actions to be implemented from the national to the local level. Atlas is a data acquisition module on the components of territory and hazards. Information on the territory of elements can be defined dynamically. Field work can be performed by non-professional operators on the basis of a clearly defined process, a method of automated synchronization and continuous quality control. Atlas can not only prepare all data needed for risk assessment, including through a drone, but it can integrate into any existing data available consistent from institutional services. The analysis modules allow discussion of the acceptable risk and resilience and thus to identify the best risk mitigation solutions. Based on the Atlas module, it was possible for a group of operators (8 people) equipped with 4 ground tablets, to acquire information on around 7,500 buildings within two months.

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1D and 2D simulations compared to experimental data to evaluate the topographic seismic site effect (Monteluco relief, L'Aquila)

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Keywords: seismic amplification, topographic effect, 1D and 2D simulations, linear-equivalent analysis.

We present the seismic site characterization of Monteluco, a NW-SE oriented flat top carbonate relief, by comparing 1D and 2D simulation and seismic data. Monteluco subsoil model has been set up by using geophysical and borehole data, fine scale geological mapping and rock mass surveys to investigate the ground motion amplification observed on the Monteluco top via microtremor and local earthquakes. We computed 1D and 2D simulations on two orthogonal NW-SE and NE-SW trending sections. The seismic input used in the modeling consists of four free field accelerograms at the bedrock as reported in Gruppo di Lavoro MS–AQ (2010). The 1D software used for simulations is the code STRATA. The linear viscoelastic model refers to the Kelvin-Voigt rheological model assuming that the shear waves propagate vertically. The equivalent linear model considers the shear modulus G and the damping ratio D as a function of the shear strain γ. Conversely, for 2D simulation we used the software LSR (Local Seismic Response 2D) which performs 2D modeling using finite element approach, in time domain and total stresses. It uses the Kelvin-Voigt subsoil model such as the more known QUAD 4M. The LSR 2D mesh calculation is friendly in case of complex geological setting such as our sections. In the 2D analysis with linear equivalent and concentrated masses approach, the subsoil model is discretized in a mesh with triangular or quadrangular shape elements. Fourier amplitude spectra obtained with 1D and 2D simulations were compared to HVSR of microtremor and local earthquakes to investigate the resonance frequency of Monteluco top.

Monteluco is an interesting case study as regards the role of topography on the seismic amplification often observed at rock sites. Thanks to simulations performed with 1D and 2D softwares, we could suggest preliminarily a seismic topographic effect. The resonance values obtained with weak motion measurements in the Monteluco flat top are within 2-4 Hz, and are likely due to a several tens of meters of fractured rocks. Simulations are in good agreement with seismic data, identifying a resonance frequency in the range of 2-4 Hz with a clear peak at 2Hz. The 2D amplification is higher than 1D (0.5 vs. 0.2), confirming the supposed topographic effect on Monteluco top. We found also an amplification increse from the NW slope toward Monteluco top. Instead, on the NE-SW section simulations evidenced a similar effect, but with a remarkable decrease in amplification with respect to the NW-SE section. Based on this evidence we could hypotize a NW-SE polarizing behavior of Monteluco as observed also by microtremor and local earthquakes which show a nearly N120°-140° polarization at Monteluco top.

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Floods, landslides and soil erosion from extraordinary meteorological events in the Benevento Province, southern Italy

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Keywords: Floods, landslides, soil erosion, Benevento, southern Italy.

In October 2015, two extraordinary meteorological events hit the Sannio district causing floods, landslides, and soil erosion. Such events were distributed on the central and southern Italy but the area that mainly suffered their effects comprised most of the Benevento Province and part of the Avellino Province. The first storm began around 10:00 p.m. of 14th October and stopped around 4:00 a.m. of 15th October and was originated by a cyclogenesis (Valente et al., 2016). Its intensity had a peak of 27.4 mm/10 min and the total cumulative amount of rainfall ranged between 60.4 mm (San Salvatore Telesino rain gage) and 415.6 (Paupisi rain gage). During this event, the weather stations distributed across the Benevento Province recorded a strong increase in temperature (maxima for the Benevento province: 24°C). The second storm began around 12 a.m. of 19th October and stopped around 21 of 20th October. Its intensity had a peak of 12.2 mm/10 min, the total amount of rainfall ranged between 31.2 mm (Rocchetta rain gage) and 146.8 (Colle Sannita rain gage). These storms triggered a combination of floods, landslides and soil erosion, that devastated 68 municipalities of the Sannio area and were responsible for two casualties, € 700 million of damage to buildings, highways and bridges (estimate from Campania region) and about € 1 billion damages to local agriculture (Magliulo and Cusano, 2016). Most of the damages caused by floods were concentrated along the segment of the Calore river valley crossing the Benevento province and along the middle and lower course of the Tammaro river. Many factories of the industrial area of Benevento were damaged or completely destroyed. Shallow earth flows, debris flows and soil slides were triggered in the central and in the northeastern sectors of the Benevento Province and many debris flows reshaped the creeks along the northern slope of the Camposauro Mount and damaged many local roads and buildings. Nearly all of the croplands of the Benevento province suffers severe soil (rill and gully) erosion and most of the sediment entrained the river network with important effects on its dynamic and morphological evolution. The events of October 2015 at Benevento have significant historical precedents, for instance i) on the 2st October of 1949 heavy rainfall induced diffuse floods and caused 20 fatalities and severe damages to building and infrastructures and ii) in May 1729, the Calore and Sabato rivers flooded the areas surrounding the town of Benevento causing extensive damages to farmlands.

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Modern Challenges Faced by Engineers in Risk Assessment and Management

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Keywords: Risk Management, Multihazard, Traditional and Innovative approaches, Stress tests

"Risk" is an abstract concept and has different definitions in different disciplines. However, regardless of its definition, risk is not static and risk assessment and management in a complex and changing world poses a number of challenges. Three of these challenges will be addressed in the keynote: dealing with the risk posed by extreme events; multi-hazard, multi-risk and cascading events; and holistic, transdisciplinary risk assessment.

The conventional methodology employed by engineers for assessing and managing the risk posed by natural and/or man-made hazards is quantitative risk assessment (QRA). In QRA one estimates the various components of risk, namely hazard (temporal probability of occurrence of a threat), vulnerability and exposure of elements of risk, and utility or value of the elements at risk, quantitatively and makes a value estimate of the expected loss. The process of QRA also sheds light on how the risk can be reduced. Other key components of risk management besides risk assessment are the notion of acceptable and/or tolerable risk, implementation of risk mitigation measures, risk communication and multi-risk issues.

The conventional approach for risk assessment and management may be inadequate when dealing with the risk posed by extreme events. Per definition, 'extreme' events are rare and largely unpredictable. Even in a statistical sense, the prediction of extreme natural hazard events involves significant uncertainties. A further complication is that extreme events do not bear a one-to-one relationship with extreme impacts. The link between an extreme physical event with an extreme impact depends strongly on context, reflecting both the degree to which populations, ecosystems and other elements at risk are located in the path of the extreme (exposure) and the underlying vulnerability or susceptibility to damage of these elements. For hydro-meteorological hazards, a central concern is that climate change has introduced substantial non-stationarity into risk management decisions. Non-stationarity is the realization that past experiences may no longer be a reliable predictor of the future character and frequency of events; it applies both to hazards and to the response of human systems to same. As climate change is expected to change the frequency, magnitude, and other characteristics of extreme events, some of which are associated with extreme impacts, risk management strategies must accommodate a shifting distribution of the latter. The keynote will propose stress testing as a compliment to traditional risk assessment for managing with the risk posed by extreme events. Stress testing is a procedure used to determine the stability of a system or entity. It involves testing the said system or entity to beyond its normal operational capacity, often to a breaking point, in order to observe its performance/reaction to a pre-defined internal or external pressure/force. Stress tests have been used for many years in air traffic safety, in particular for airplanes and helicopters. In recent years, stress testing has often been associated with methodologies to assess the vulnerability of a financial system or specific components of it, such as banks. Properly designed stress tests can help detect the weak points in the system under the action of extreme events and identify measures that would remedy the weaknesses and make the system more robust. Many extreme events are result of complex hazard interactions, triggering or cascade effects. A typical example of such cascading effects is the Great East Japan Earthquake of March 2011, which triggered a tsunami that in turn led to the Fukushima Dai-ichi nuclear power plant accident. This type of cascading events is often neglected in risk management scenarios. The necessary input data, and sometimes the complexity of the hazard 'chains' that can be foreseen, discourage the analyst to consider such interactions and triggering effects in a holistic multi-risk analysis. However, recent research on multi-hazard and multi-risk assessment has provided a number of tools, like Bayesian networks, to analyse and manage the risk posed by cascading hazard scenarios.

Another type of challenge faced by engineers in large, multi-disciplinary projects is that risk has many facets and experts in different disciplines do not necessarily agree on what are the most important elements at risk or what metrics should be used to quantify the risk. In November 2015, Roskilde University (Denmark) hosted a workshop on "Environmental Risk – Assessing and Managing Multiple Risks in a Changing World". The consensus recommendations of 30 attendees with variety of backgrounds from 9 countries at the Roskilde workshop was implementation of "ecosystem services" as a common currency for holistic environmental risk assessment and management. The concept of ecosystem services started by environmental economists, but is being used more and more by natural scientists. In a complex and changing world, this will become more and more important as an element to be included when assessing the costs and benefits of different risk management alternatives, especially those that damage/remove nature and the services nature provides.

The ideas put forward in the keynote lecture for dealing with these challenges are still being developed and it may take several years before the tools and methodologies for dealing with these challenges are validated and accepted by the risk management specialists. However, there is no doubt that society must adapt to the ever-changing risk patterns, and it is our duty to develop and test innovative risk assessment and management methods to address these challenges.

Seismic microzoning of the historical centre of Napoli

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Keywords: Ground motion modeling, 1688 and 1980 earthquakes, historical centre of Napoli.

Napoli is a densely populated city founded by Greek settlers in 470 B.C. and with a relevant heritage (UNESCO World Heritage Site since 1995), close enough to a seismogenic area to suffer serious damage. Following the CPTI11 earthquake catalogue, the maximum felt intensity at Napoli is VIII (MCS) and is related to the Sannio-Matese seismogenic area with 1456 and 1688 earthquakes. The closeness of the epicenters and the similar attributed magnitude, beside uncertainty regarding the 1456 event (probably composed by at least 3 sub-events) suggested to consider the 1688 seismic event as the strongest earthquake scenario for Napoli. Damage intensity VII-VIII (MCS) was caused by the last strong 1980 (Irpinia) earthquake (M_W=6.9).

A realistic estimate of the expected ground motion at the historical centre of Napoli is done along two-dimensional sections with a hybrid method (mode summation plus finite difference) which takes into account source, propagation and local site effects by using principles of physics about wave generation and propagation in complex media. The use of the hybrid method is fully justified by the good knowledge of the geological and geophysical properties of the neapolitan subsoil. The geological setting of the historical centre of Napoli is mainly characterized by a cover of man-made ground, alluvial and pyroclastic soils overlying the horizon of Neapolitan Yellow Tuff (NYT) both in lithoid and loose facies. Such setting is quite complex because of the presence of several cavities in the lithoid facies of NYT. Moreover, in the framework of projects STRESS-METRICS and DATABENC-SNECS, several noise cross-correlation measurements have been carried out for the definition of shear wave velocity models up to a few hundreds of metres.

Ground motion parameters have been computed along two-dimensional sections for the 1980 and 1688 earthquakes. Ground motion for the 1980 event has been computed (Nunziata, 2004) after validation of synthetics with earthquake recording at Torre del Greco, about 12 km far from Napoli, while the 1688 event has been modeled after validation of synthetics with recording at the historical centre (SMN station, www.ogsism.unina.it) of a moderate (M_W=5.2) earthquake, nucleated in the northern sector of the 1688 fault, in December 2013.

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Natural Asbestos Occurrence in serpentinite-metabasite lithotypes and in agricultural soils derivate: an example from Calabria, southern Italy

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Keywords: Natural Occurring Asbestos, serpentinite, metabasite, soil, Calabria (Italy).

The present research focuses on serpentinite-metabasite bedrocks and derivate soils, which could potentially be rich in regulated (asbestos) and non-regulated fibrous minerals and, as a consequence, have a negative impact on agricultural and anthropic activity and on environmental quality (Bloise et al., 2016).For this reason, we chose some serpentinite and metabasite–key outcrops such as those ones located at quarries, road cut and nearby soils sitting in the area of Gimigliano and Conflenti towns (Sila Piccola, northern Calabria), of asbestiform minerals that could be potentially harmful for human health. From outcrops, serpentinite and metabasite rock samples and ten agricultural soils have been collected and investigated in detail by means of Polarized Light Microscopy (PLM), X-ray powder diffractometry (XRPD), scanning and transmission electron microscopy combined with energy dispersive spectrometry, analytical electron microscopy (SEM–EDS and TEM–AEM), differential scanning calorimetry (DSC), thermogravimetric (TG) and by μ-Raman spectroscopy (μ-R). Results revealed that, when natural outcrops are disturbed by human activities, the weathering processes and consequent release of NOA in the environment may be enhanced. In particular, serpentinites cropping out near to Gimigliano and Conflenti towns act as a perennial source of contamination for the agriculture lands. Indeed, analyses showed the presence of a relatively large amount of chrysotile, fibrous antigorite and asbestos tremolite on the surface of the related soils. Even if they usually occur in aggregates which cannot be suspended in the air, agricultural activities can destroy these soil aggregates with the creation of dust containing inhalable asbestos fibres that evolve into airborne increasing the exposure to them by population. Finally, since the dispersion of fibres could be associated with one or more respiratory diseases (asbestosis, mesothelioma, lung carcinoma), in our opinion further research on serpentinite-metabasite (i.e. ophiolite) lithotypes is required, in order to assess the non-occupational lifelong exposure of population to Natural Occurring Asbestos.

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Susceptibility analysis of rainfall-induced shallow landslides in the city of Rome (Italy) through a physically-based approach

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Keywords: Rome, shallow landslides, heavy rainfall, physically-based model, TRIGRS.

Due to its geological and geomorphological features, the city of Rome (Italy) is exposed to different types of geological risks, including the hydrogeological risk. In this respect, landslides triggered by intense rainfall events are phenomena that frequently affect the hills on which the city rises, often causing damage to buildings and infrastructure. There is therefore a need to develop new methods and techniques that can provide useful insights to support the Authorities in landslide risk management. In a recent publication (Schilirò et al., 2015), we propose a physically-based approach for the definition of shallow landslide-triggering scenarios. In the light of that work, here we present the results of the application of the same approach in Rome urban area. Specifically we used TRIGRS, a numerical model designed for forecasting the timing and distribution of rainfall-induced shallow landslides (Baum et al., 2008), with the aim of reproducing the landslide event occurred in the study area from 31 January to 2 February 2014. The input parameters of the model have been evaluated using the field data collected on the reliefs of Monte Mario and Monte Ciocci. After calibrating the model through the back-analysis of the 2014 event, different triggering scenarios have been defined using rainfall values derived from the rainfall probability curves, reconstructed on the basis of daily and hourly historical rainfall data (Alessi et al., 2014).

Alessi D., Bozzano F., Di Lisa A., Esposito C., Fantini A., Loffredo A., Martino S., Mele F., Moretto S., Noviello A., Prestininzi A., Sarandrea A., Scarascia Mugnozza G., Schilirò L. & Varone C. 2014. Geological risks in large cities: the landslides triggered in the city of Rome (Italy) by the rainfall of 31 January-2 February 2014. Italian Journal of Engineering Geology and Environment, 1, 15-34.

Baum R.L., Savage W.Z. & Godt J.W. 2008. TRIGRS - A Fortran program for transient rainfall infiltration and grid-based regional slope-stability analysis, version 2.0 U.S. Geological Survey, Open-File Report 2008-1159, 75 pp.

Schilirò L., Esposito C. & Scarascia Mugnozza G. 2015. Evaluation of shallow landslide triggering scenarios through physically-based approach: an example of appliction in the southern Messina area. Natural Hazards and Earth System Sciences, 15, 2091-2109.

Does a seismic double-resonance affect L'Aquila historical downtown buildings?

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Keywords: seismic hazard, microtremor, subsoil model, damage building distribution, double resonance effect.

We present for L'Aquila downtown the comparison between microtremor recordings, the distribution map of the shallow geological units and of the building damage distribution caused by the recent April 6th 2009 (Mw: 6.1) and the more severe February 2 1703 (Mw: 6.7) earthquakes. This comparison permits to understand deeply the seismic site characterization of a high seismic hazard urban area of Central Apennines, such as L'Aquila downtown.

L'Aquila downtown stratigraphy is composed downward by (i) 2-20 m thick of Holocene-Upper Pleistocene soft soil (Red colluvium and Anthopic fill); (ii) 20-100 m thick of calcareous breccia (Middle Pleistocene) which represents the relief on which L'Aquila downtown lays; (iii) 200 m thick of pelite and sand (Lower Pleistocene); (iv) Meso-Cenozoic carbonate bedrock (Del Monaco et al., 2013).

The HVNSR analysis of about 300 microtremor recordings identifies two resonance frequencies, f0 (0.4-0.7 Hz) and f1 (4-9 Hz). 1D and 2D numerical simulations evidences that the origin of f0 and f1 is caused by two main geophysical impedance contrasts. f0 is due to the superposition of pelite and sand onto the carbonate bedrock at 200-300 meters above ground level. f1 is caused by shallower impedance contrast due to 3-20 m thick of Red colluvium and Anthopic fill onto calcareous breccia.

While the seismic significance of f0 was already analyzed in detail, then our study was focused on the relationships between the shallow subsoil model, f1 and building damage distribution. We elaborated via ArcGis the map of the bottom surface of Red colluvium and Anthopic fill accountable for f1 resonance frequency, the maps of the f1 contour lines and the building damage distribution for the April 6 2009 and February 2 1703 earthquakes (Clementi & Piroddi, 1986; Tertulliani et al., 2011).

The distribution of Red colluvium and Anthopic fill matches with f1 contour line map, as it was to be expected. Unexpectedly, their distributions fit with the severe building damages distribution of the above mentioned earthquakes taking also into account that the building frequencies of L'Aquila downtown are roughly in the range of f1 values. So that we can hypothetically conjecture a double resonance effects between soil and buildings for L'Aquila historical downtown.

Clementi A. & Piroddi E. 1986. L'Aquila. Laterza, Roma-Bari.

Del Monaco F., Tallini M., De Rose C. & Durante F. 2013. HVNSR survey in historical downtown L'Aquila (central Italy): site resonance properties vs. subsoil model. Engineering Geology, 158, 34-47.

Tertulliani A., Arcoraci L., Berardi M., Bernardini F., Camassi R., Castellano C., Del Mese S., Ercolani E., Graziani L., Leschiutta I., Rossi A. & Vecchi M. 2011. An application of EMS98 in a medium-sized city: the case of L'Aquila (Central Italy) after the April 6, 2009 Mw 6.3 earthquake. Bulletin of Earthquake Engineering, 9, 67–80.

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Up-to-date L'Aquila town subsoil model for seismic site and hazard evaluation: boreholes and single station microtremor data to investigate the Pettino Fault

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Keywords: seismic site characterization, subsoil model, geological mapping, borehole logs, microtremor, GIS.

The seismic site response needs of a well constrained subsoil model, therefore in urban areas, as L'Aquila town, boreholes data and geophysical investigations are so useful because of buildings and anthropic elements cover surface geology. Furthermore, several speculations concern the crossing of the Pettino Fault in L'Aquila town. This fault is considered active (Galli et al., 2011), so its crossing regards also the seismic hazard evaluation of L'Aquila town. Taking into account this preamble, our goal has been to fine tune the subsoil model of L'Aquila town by means of several hundreds of boreholes logs and single station microtremor data which have been integrated with geological observations in L'Aquila town and its neighbourhood. Boreholes were carried out for the reconstruction activities caused by the building damages due to the April 6 – Mw: 6.1 L'Aquila earthquake, while we acquired geological and microtremor data for research purposes and specific projects (Del Monaco et al., 2013; Nocentini, 2016). A fine scale geological mapping, borehole and microtremor data were organised into a GIS which facilitated our elaborations. Summarising, the preliminary results permitted to recognize in L'Aquila town two zones characterised by different subsoil models which are put beside roughly along a probable south-eastward splay of the Pettino Fault. The subsoil model of the northern zone consists of 20-30 thick of middle Pleistocene L'Aquila breccia laying upon Meso-Cenozoic limestones. The southern zone is characterised by 60-100 m of L'Aquila breccia laying upon 200-300 m thick of fluvial pelite and sand pertaining to middle Pleistocene Fosso Genzano Synthem and early Pleistocene Madonna della Strada Synthem (Nocentini, 2016). The Quaternary cover lays upon Meso-Cenozoic limestones. This up-to-date subsoil model which consists of two geologically different zones bounded by a splay of the Pettino Fault is promising considering also the results of thorough microtremor array measurements (see Fig. 7 in Di Giulio et al., 2014).

Del Monaco F., Tallini M., De Rose C. & Durante F. 2013. HVNSR survey in historical downtown L'Aquila (central Italy): site resonance properties vs. subsoil model. Engineering Geology, 158, 34-47.

Di Giulio G., Gaudiosi I., Cara F., Milana G. & Tallini M. 2014. Shear-wave velocity profile and seismic input derived from ambient vibration array measurements: the case study of downtown L'Aquila. Geophys. J. Int., 198, 848-866.

Galli P.A.C., Giaccio B., Messina P., Peronace E. & Zuppi G.M. 2011. Palaeoseismology of the L'Aquila faults (central Italy, 2009, Mw 6.3 earthquake): implications for active fault linkage. Geophys. J. Int., 187, 1119-1134.

Nocentini M. 2016. Integrated analysis for intermontane basins studies: tectono-stratigraphic and paleoclimatic evolution of the L'Aquila Basin. PhD thesis in Environmental and Resources Geology, University of Roma Tre (XXVII cycle).

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Remote sensing and geophysics for a multidisciplinary approach to the stratigraphic reconstruction to support the preliminary project of a new settlement (the case study of Kintélé – Republic of Congo)

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Keywords: Geophysical Surveys, Remote Sensing, Congo.

This study is part of the preliminary and final planning of an integrated urban plan on a new site for many thousands housings on an area of more than 500 Ha, located in Kintélé, Brazzaville (Republic of Congo). Our phase of preliminary project required a multidisciplinary studies, characterized by the integration of geological, geotechnical, geophysical fieldworks, and remote sensing analyses. Beside to the geological works, the goal of geophysical surveys is to detect, evaluate and model the superficial geo-stratigraphical structure. Aims of surveys were:

- Geological reconstruction and update the existing geological map;
- Reconstruction of deep structures and terrain seismic characterization.

The work started with an accurate photo-geological interpretation trough images acquired from satellite in the visible and near infrared sections of electromagnetic spectrum (space borne images database offer by Google and the archived scene acquired by French satellite Pleiades 1A). This interpretation was finalized to interpret the main geomorphologic structures of the area and to detect the main geological features. The results of this phase were verified and updated by means of a detailed geological fieldwork.

Active seismic methods in-array and single station passive methods allowed us to reconstruct the relatively deep structure, through the followings techniques: 11 seismic refractions in P-waves (array of 48 geophones, 14 Hz, 10 m of interdistance), 25 MASW profiles (with 24 geophones, 4.5 Hz, 3 m of interdistance), 74 HVSR graphs obtained from seismic noise recorded by passive single station measurements (with a 128Hz sample frequencies for 20 minutes). Geophysical data were processed taking into account also the available results of the direct investigations (boreholes and pressiometric tests) assumed as stratigraphical constrains.

The results of active and passive seismic surveys underline each other the presence of two seismostrates with a contact depth from 35 to 40m below the ground level. Geological fieldworks and boreholes logs show the presence of silty-sand layer for the thickness investigated by seismic surveys, so the increasing of acoustic impedance is related to a variability of layer compaction. This variation is also proved by results of the performed pressiometric tests, which show an increasing of elastic modulus corresponding to the growing of acoustic impedance. In summary, the results of this study showed the substantial feasibility of the urban plan designed for Kintélé, of course subject to the necessary structural adjustments.

Modelling of earthquake induced deformations in alluvial deposits at Rome (Italy)

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Keywords: Earthquake-induced effects, shear strains, numerical modelling, Rome, alluvial deposits.

Seismically induced effects are a major topic for scientific community since last decades. Relevance of ground motion amplifications as well as of earthquake-induced permanent deformations represents a fundamental issue for engineering applications and, more in particular, for technical rules regulating the building design. This paper focuses on the evaluation of earthquake-induced shear strain distribution in recent alluvial deposits through a numerical approach. The chosen case study is the city of Rome that hosts an invaluable historical and cultural heritage. The geological setting of the Rome's urban area resulted by different geological processes (i.e. tectonic, fluvial and volcanic) occurred since the last 10M yrs to Present. The city of Rome is characterized by a moderate felt seismicity which is related to a maximum M 7 earthquake located in the Central Apennine (about 100km far from Rome). Several studies have been focused so far on the local seismic response in the Rome urban area and pointed out that the heterogeneous composition of the alluvial deposits of the Tiber River and its tributaries is responsible for both 1D amplification effects, mainly related to soil stratigraphy, and 2D amplification effects that can be related to wave refraction at the edge of the valley as well as to lateral heterogeneities, responsible for not negligible impedance contrasts.

Preliminary results of numerical approaches carried out by 1D and 2D numerical codes are here presented regarding the earthquake-induced shear strain distribution in the recent alluvial deposits of the Tiber River as well as of its tributaries. Both Boundary Element Method (BEM) and Finite Element Method, the latter involving a novel absorbing layer approach, have been applied. Natural accelerograms were used as seismic input for numerical modelling. To output the effects of lateral heterogeneities on the shear strain concentration within the alluvial deposits, the modelled maximum shear strains (MSS) have been computed for the different litothecnical units as well as their concentration, in case of both homogeneous and heterogeneous fill conditions. The obtained results show that, in terms of seismically-induced strain effects, the role of lateral heterogeneities within the deposits is prevalent respect to the one due to the alluvial valley shape.

SESSION S26

Remote sensing for the Geosciences and the Environment

CONVENERS AND CHAIRPERSONS

Francesca Bozzano (Università di Roma La Sapienza)
Domenico Calcaterra (Università di Napoli Federico II)
Alessandro Ferretti (TRE Europa)
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First tests of Imaging rover techniques for the geomatic restitution of a sinkhole: the test site known as "Pozzo del Merro"

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Keywords: Sinkhole, Merro, DTM, Geomatic, GPS, imaging rover.

The sinkhole known as "Pozzo del Merro" possesses unusual, if not unique, geological and natural features, providing an important opportunity to study the geological and hydrological characteristics of the area, and at the same time to preserve an ecosystem inhabited by species that, as far as we know, are found nowhere else. The site has been the object of numerous studies carried out by scholars from a wide range of disciplines (Floris et al. 2014), but a true morphological survey has not been performed until now due to logistical difficulties that include the lack of adequate measuring positions and the difficulty of establishing a clear view between points. The availability of an imaging rover (Trimble V10) an innovative photogrammetric multifocal instrument integrated with a GPS/GNSS double frequency receiver suggest to perform the survey to experiment this completely new technology, comparing and assessing with more consolidated methodologies.

The instrument tested consists of an integrated camera system that captures a 60 MP 360-degree digital panoramas; each acquisition is performed with a total of 12 calibrated photogrammetric cameras – seven panorama and five downward-looking. The GPS accuracy (H 8 mm + 1 ppm, V 15 mm + 1 ppm; - Trimble (2016)). With this configuration, after a single photogrammetric acquisition, the position of the instrument is given, but not its azimuth, so more stations are needed. The photogrammetric automatic algorithm has extracted almost completely the parts of sinkhole without foliage cover that represents a very small area with respect to the whole sinkhole, reporting accuracy mostly lower 5-6 cm. compatible with declared accuracy for similar distances; the survey did not identify secondary emerged cavities or tunnels that had been hypothesized on the basis of those found above water. Nonetheless, due to the specific morphology of the site, the presence of other undiscovered morphological characteristics cannot be ruled out. The Imaging rover instrumentation showed that the accuracy is similar to laser scanner, the imaging rover has a wider vertical field of view, it is logistically much more versatile and it can be of strategic importance in such sites with complex morphologies. On the other hand Imaging rover has no capabilities of penetrating foliage that is a drawback, particularly in some periods of the year.

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www.trimble.com, last visited may 03 2016.

Assessment of the geomorphodynamic evolution of the Boulder Clay Glacier area (Terra Nova Bay, Antarctica) by SAR spaceborne interferometric analysis

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Keywords: remote sensing, spaceborne SAR interferometry, periglacial geomorphology, Boulder Clay Glacier.

The increased logistic operations at the Italian Research Station 'Mario Zucchelli' (MZS, Terra Nova Bay, Antarctica) are making it necessary to build an inland airstrip at the MZS's disposal. At present, logistics are relying on a seasonal ice-based airstrip, thus making the timeframe of operations extremely limited, as it happened in 2005 (PNRA CEE, 2015). The Boulder Clay Glacier (BCG) and, especially, its frontal shear moraine, an ice-cored body of debris, which is located 7 km south-west of the MZS, is among the areas considered as construction sites. The BCG is a polar cold-based glacier, located on a morpho-structural bench-like depression, that elongates in the north-south direction for 4.5 km and flows eastward and southward (Chinn et al., 1989). The ice-cored moraine is characterized by several supra-glacial lakes (SLGs), whose size range from few to tens of meters, many of which are affected by ice-blistering (Guglielmin et al., 2009). Based on Chinn (1991), the BCG is actively deforming its frontal shear moraine. In order to accurately quantify the magnitude, the spatial distribution and temporal pattern of the displacement, a Synthetic Aperture Radar spaceborne interferometric analysis was performed, thus allowing to understand the potential disturbance between active landforming processes and the planned airstrip. A stack of 102 images (average temporal resolution ~ 8 days) acquired between February 2013 and December 2014, by COSMO-SkyMed, an EO mission run by Italian Space Agency (ASI), was analyzed by DInSAR (Differential Interferometric SAR) and A-DInSAR (Advanced Differential Interferometric SAR) processing methods. The achieved results were compared with available data from GPR (Ground Probing Radar) and DGPS (Differential Global Positioning System) surveys carried out by PNRA scientists during Italian Antarctic Expeditions XXIX and XXX (2013-14 and 2014-15). Achieved results highlight the strong structural constraint (i.e. articulated bedrock's buried structures) that drives the direction and magnitude of the glacier flow, with surface velocities ranging from few cm to 1 m per year and the localized activity of the SGLs affected by ice-blistering.

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Application of Persistent Scatterer Interferometry technique to estimate the Chalk aquifer properties in the London Basin

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Keywords: Persistent Scatterer Interferometry (PSI), Chalk aquifer storage, London.

The Chalk aquifer in London has been exploited for public and industrial supply since the 1850s and is one of the most monitored and managed aquifer-systems in the United Kingdom (UK). Although several authors have previously investigated the hydraulic properties of the Chalk aquifer using traditional field, experiments and laboratory measurements, characterization of the Chalk aquifer properties resulting from the presence of discontinuities, and across large spatial-scales, is still a complex task.

In this paper, we perform Persistent Scatterer Interferometry to ERS-1/2 and ENVISAT satellite data covering 1992-2000 and 2002-2010 respectively, to investigate the relationship between ground motion and hydraulic head changes across the London Basin (UK). Chalk aquifer storage and compressibility in London were estimated by the use of PSI data over an area of ~1,360 km^2.

The results reveal that the variations in storage coefficient are correlated with changes in hydraulic head and the hydrogeological setting of confining layers. As a consequence, different policies and zonal planning for certain parts of London are essential to manage the available resource.

Multi-sensor SAR data for landslide inventory updating: the case study of Piemonte Region

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Keywords: Interferometry, landslides, Principal Component Analysis.

In the last decade, satellite radar differential interferometry (DInSAR) has been used in updating the landslides inventories. The technique allows to monitor the deformation patterns over large areas, in order to verify and/or modify the landslide boundaries. Moreover, it contributes to define the state of activity of a phenomenon. The improvements of the SAR data, guaranteed by the COSMO-SkyMed satellites and by the future ESA Sentinel missions, that act at higher spatio-temporal resolution, require appropriate methodologies for analyzing large datasets of points of measures.

To address to these problems, we present a guiding procedure to analyze multi-sensors SAR dataset with the aim of updating landslides inventories. We applied the methodology in Piemonte region, a wide area of north-western Italy affected by a big amount of different types of landslides. We use satellites images acquired, in ascending and descending acquisition geometry, by C-band (ERS ½, ENVISAT, RADARSAT) and X-band (COSMO-SkyMed) sensors and processed using SqueeSAR™, PSInSAR™ and PSP-IfSAR techniques. The project was carried out in collaboration with ARPA Piemonte and a part of the interferometric data were provided by the Italian Ministry of Environment in the frame of the "Extraordinary Plan of Environmental Remote Sensing" (PST-A).

The developed methodology consists of three main steps: 1) post-processing elaborations of the SAR data, for removing possible errors which could affect the dataset; 2) identification of the ground motion areas characterized by different deformation style (i.e. lowering, uplift and non-linear trend) by the use of automatic and semi-automatic statistical analysis, based on Principal Component Analysis, on the displacement time series; 3) analysis between the identified ground motion areas and the landslides distribution (The Piemonte Landslide inventory–SIFRAP) both at regional scale and at local scale, thanks to detailed *in situ* analysis for the most interesting sites.

Integrating multi-sensor SAR data collected for a continuous period of 24 years (from 1992 to 2015) provided important information on the landslides detection at regional and local scales, in the different geological, geomorphological and environmental contexts of the Piemonte region. Three study areas, where SAR images of all the considered sensors were available, were selected for representing the main contexts of Piemonte region: the Susa (528 km^2 wide) and the Orco-Lanzo (996 km^2 wide) valleys, representative of the Alps domain; the western Turin hill (404 km^2 wide), representative of the Turin hill context. The availability of the large archive of SAR data allowed the back-monitoring of the time evolution of different phenomena. In particular, different phases of activation, re-activation, acceleration or stabilization of the phenomena were recognized. In addition we have assessed the performance of the multi-sensors SAR data for monitoring different landslides types.

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UAV photogrammetric survey of the Poggio Baldi Landslide (Santa Sofia, North Apennine, Italy)

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Keywords: Landslide monitoring, UAV-photogrammetry, Structure from Motion (SfM), DSM, GPS, Remote Sensing.

On 19th March 2010, a re-activation of an ancient landslide occurred in Poggio Baldi, a small village located near Corniolo, in the municipality of Santa Sofia (FC, Italy). Its previous catastrophic activation is dated back to March 1914. The 4 million m^3 landslide is considered a real hazard, because during its last re-activation produced several serious damages on some private constructions and on the 310 Statal Road, but caused also a natural dam on the Bidente River.

With a height-range between 810 – 480 m asl, the Poggio Baldi landslide involved the "*Marnoso – Arenacea Romagnola*" Formation, arenite-pelite alternation [*Burdigalian$_{sup}$* – *Langhian*]. Started as a structurally controlled rockslide, it then evolved as a partially confined flow-like landslide affecting the material originally mobilized by the 1914 landslide.

The landslide area is now made of a high vertical rock cliff up to 100 m high and about 250 m large, a rock debris on the order of 1.5*10^5 m^2 at the toe of the cliff and an extensive mixed rock-earth debris mobilized by the 2010 landslide.

Thanks to the joint effort of NHAZCA S.r.l., spin-off of the University of Rome "Sapienza", the Department of Earth Sciences of the University of Rome "Sapienza" and Visiva4D, the experimental site of the Poggio Baldi landslide was surveyed on 12th April 2016 by a UAV flight. The employed UAV was a DJI Phantom 4 equipped with GPS and IMU apparatus. 12 MPx camera, with a 1/2,3'' sensor size, equipped with a 20 mm lens, was used. Four flights were performed in order to generate accurate DSM of the entire site, by acquiring about 950 images. Due to the wide coverage, caused by the mountainous area, no satellite signals were available. For this reason all the flights were executed in manual mode. The orientation of the UAV flights were carried out by means of 12 ground control points, measured with a GeoMax Zenith 25 Pro GPS/GNSS Base and RTK Rover.

The collected images was processed by suitable Structure from Motion (SfM) algorithms in order to achieve an accurate digital elevation model (DEM) of the whole landslide. The comparison of the acquired DEM with previous available DEM, achieved by Aerial and Terrestrial LiDAR surveys, allowed to evaluate the quality of the overall UAV DEM and, then, to compute the morphological changes occurred in the landslide area.

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Temperature remote sensing of submerged calderas: an application to off-shore sector of Campi Flegrei caldera (Southern Italy)

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Keywords: temperature monitoring, caldera, optical fiber, scattering Brillouin.

In the framework of MON.I.C.A project (Innovative Monitoring for Coastal and Marine Environment), an advanced underwater temperature monitoring system has been installed in the active caldera of Campi Flegrei, by using an optical fiber cable deployed on the sea floor and exploiting the stimulated Brillouin scattering (Kobyakovet al., 2010). This allowed us to obtain a first temperature profile 2400m extended along the off-shore active caldera of Campi Flegrei (Gulf of Pozzuoli). The system consists of a reinforced multi-fiber cable containing 6 single-mode telecom grade optical fibers which provides a distributed temperature sensing with 1m of spatial resolution. The obtained data show that the off-shore caldera is thermally very active, at least along the monitored profile, with a good correlation in comparing the temperature profile with the main structural features inferred from high-resolution reflection seismic surveys. This represents an important advancement in the monitoring of this high risk volcanic area, since temperature variations are among the precursors of magma and/or hot fluids migration towards the surface. The adopted system can be also applied to others worldwide hazardous calderas, which are often partially or largely submerged and are difficult to monitor.

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The 2012 Emilia earthquake sequence (Northern Italy): evidence for fault activation and stress transfer between en echelon thrusts from a new geodetic dataset

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Keywords: 2012 Emilia earthquake sequence, DInSAR, SBAS, Fault activation, Stress transfer.

We show the results of the inversion of a new geodetic dataset, involving both remote sensing and ground-based data: high precision levelling data, GPS observations and Differential Synthetic Aperture Radar Interferometry (DInSAR) products covering the 2012 Emilia seismic sequence and the following one year of post-seismic deformation. As far as DInSAR analysis, we used data acquired by the RADARSAT-2 (RSAT2) satellite from the Canadian Space Agency and by the COSMO-SkyMed (CSK) constellation developed by the Italian Space Agency in cooperation with the Ministry of Defense. For what attains the RSAT2 mission, we considered a single interferometric pair only, involving the 30 April and 17 June 2012 stripmap acquisitions, aimed at measuring the cumulative coseismic ground displacement due to the two mainshocks (20 and 29 May 2012). As for the CSK mission, a dataset of 12 stripmap images covering a time interval of almost one year, from 27 May 2012 to 7 May 2013, allowed measuring the coseismic displacement field relevant to the 29 May mainshock as well as one year of post-seismic deformation. To retrieve the CSK deformation time series relevant to the post-seismic sequence, we applied the Small BAseline Subset (SBAS) algorithm (Berardino et al., 2002), specifically the one in Fornaro et al. (2009). By use of the geodetic dataset together with a catalog of relocated aftershocks, we modeled rupture geometries, and the coseismic and post-seismic slip distributions for the two main events (M_W 6.1 and 6.0) of the sequence, allowing us to suggest the influence of structure and/or lithology on slip propagation in intracontinental settings. Moreover, we explored how these thrust events have interacted with each other and, defining the Coulomb stress changes, how first mainshock triggered following activity. Our results also indicate that between the two main events, a third thrust segment was activated by first mainshock, releasing a pulse of aseismic slip equivalent to a M_W 5.8 event. We also hypothesized that the aseismic slip event probably brought the second fault closer to failure. Generally, we found that among continental en echelon thrusts, stress transfer and interaction between earthquakes and aseismic slip may play an important role in the way they activate during a seismic sequence.

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Applications of the MetaSensing's FastGBSAR for vibration and deformation monitoring

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Keywords: interferometric radar, SAR, structural monitoring, terrain deformation monitoring, RAR.

The knowledge of structural movements and terrain activities is essential to construction and geotechnical engineers. The use of instruments which can help in understating the mechanisms responsible for such phenomena is becoming of primary importance. Moreover, in order to prevent hazardous and harmful situations, a continuous monitoring is often needed for risk management in critical environments, such as dikes, dams, landslides, open pit mines, bridges, or towers. The MetaSensing's FastGBSAR (Fast Ground-Based Synthetic Aperture Radar) allows for the continuous monitoring of deformation and vibration of natural and man-made structures at the fastest scanning rate available on the market. It is a ground based interferometric radar system that can operate during day and night and it can penetrate fog and clouds, thanks to the use of microwaves (Ku frequency band).

The FastGBSAR can operate in two modes

- Real Aperture Radar (RAR): The radar unit is installed on a tripod and delivers displacement time-series with sampling frequencies of up to 4 kHz, ideal for monitoring vibrations at buildings and structures.
- Synthetic Aperture Radar (SAR): The radar unit is moving along a linear rail and produces two-dimensional displacement maps with an acquisition time of less than 5 seconds. By that, displacement time series with a high temporal and spatial resolution can be generated, giving detailed information to determine the deformation mechanisms involved and to predict a possible upcoming failure.

Depending on the application, the radar unit can be configured in two different hardware versions:

- Standard version for deformation monitoring with two antennas (one transmitting, one receiving) both vertically polarized.
- Polarimetric version with two transmitting and two receiving antennas (vertically and horizontally polarized). This allows for the acquisition of fully polarimetric data (VV, VH, HV, HH) for retrieving additional information about the features of the terrain.

Displacement time series with a high temporal and spatial resolution can be generated, making it possible to predict potential failures.

Thanks to the fast acquisition rate and by means of processing interferometric images in near real-time, the deformations occurring in between two acquisitions can be quickly derived with sub-millimeter accuracy. The system is robust and versatile, and it can be used for many applications, like stability assessment and structural testing.

Some examples of use of the FastGBSAR for real-time deformation and vibration and monitoring of man-made and natural structures will be shown during the presentation.

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Remote sensing and deformation paths analysis: a PSP SAR interferometry application in the archaeological site of Pompeii

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Keywords: Remote Sensing, Sar Analysis. Cultural Heritge, Pompeii.

The "Major Project Pompeii" (MPP) is a great collective commitment of different institutions and people to set about solving the serious problem of conservation of the largest archaeological sites in the world. The ancient city of Pompeii with its 66 hectares, 44 of which are excavated, is divided into 9 regiones (district), subdivided in 118 insulae (blocks) and almost 1500 domus (houses), and is UNESCO site since 1996. The Italian Ministry for Heritage and Cultural Activities and Tourism (MiBACT) and Finmeccanica Group have sealed an agreement whereby the Finmeccanica Group will donate innovative technologies and services for monitoring and protecting the archaeological site of Pompeii. Moreover, the Italian Institute for Environment Protection and Research (ISPRA) – Geological Survey of Italy, was also involved to support the ground based analysis and interpretation of the measurements provided by the industrial team, in order to promote an interdisciplinary approach. In this work, we will focus on ground deformation measurements obtained by satellite SAR interferometry and on their interpretation. The satellite monitoring service is based on the processing of COSMO-SkyMed Himage data by the e-Geos proprietary Persistent Scatterer Pair (PSP) SAR interferometry technology. The PSP technique is a proven SAR interferometry method characterized by the fact of exploiting in the processing only the relative properties between close points (pairs) in order to overcome atmospheric artifacts (which are one of the main problems of SAR interferometry). Validations analyses settled that this technique applied to COSMO-SkyMed Himage data is able to retrieve very dense (except of course on vegetated or cultivated areas) millimetric deformation measurements with sub-metric localization. By means of the COSMO-SkyMed PSP SAR interferometry processing, a historical analysis of the ground and structure deformations occurred over the entire archaeological site of Pompeii in the period from 2010 to 2014 was initially performed. Moreover, the deformation monitoring is continuing with monthly updates of the PSP analysis with new COSMO-SkyMed acquisitions both in ascending and descending geometry. The first results of the preliminary analysis over the archaeological site of Pompeii did not show large areas affected by deformations. However, the COSMO-SkyMed PSP SAR interferometry analysis proved to be very efficient due to its capability of providing a large number of deformation measurements over the archaeological site with relatively small impact and cost. Recent instability processes, both for the unexcavated slopes and for the archaeological structures, have promoted this low-impact analysis, aimed at identifying deformation paths and to prevent sudden collapses. Finally, the results obtained from the satellite techniques, will be also used to implement and improve the ground based geotechnical monitoring and warning system recently installed in selected case studies. Cross analysis between interferometric results, meteorological data and historical data of the site (e.g. collapses, works, etc.) are in progress in order to define provisional model aiming at an early identification of areas subjected to potential instability.

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Monitoring glacier albedo from space: evaluating trends and drifts from MODIS time series

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Keywords: glacier, albedo, satellite, mass balance.

The widespread shrinkage of midlatitude glaciers is largely thought to be forced by air temperature and precipitation patterns. Beyond these drivers, snow and ice albedo also plays a fundamental role in defining the annual surface mass balance of glaciers. The albedo is involved in complex feedback processes in which it is influenced by both ice melting and deposition of light-absorbing impurities. These depositions can have a local (e.g. fine dust from lateral moraine) or a distal (black carbon from combustion and mineral dust from deserts) source. In this contribution, we test the hypothesis that glaciers in the European Alps are getting darker because of multiple processes like melting and surface dust accumulation. We analyzed long time series of NASA MODIS (MODerate resolution Imaging Spectrometer) daily snow albedo product (spatial resolution 500 m) from Terra (MOD13A1, 2000-2015) and Aqua (MYD13A1, 2002-2015) satellites. We calculated the per-pixel negative linear and nonlinear trend of the summer albedo values for glaciers in the whole Alpine chain. MODIS sensor onboard the Terra satellite is known to display a negative drift due to sensor degradation, we evaluated this drift studying the trends in glaciers high accumulation zones (expected to be an invariant target), comparing data from Terra and Aqua satellites and comparing MODIS Terra data from the Collection 5 and the new Collection 6 (drift corrected). Finally, in order to evaluate the relationship between albedo and glacier mass balance, we calculated the linear correlation between MODIS summer albedo values and glaciers surface mass balance (from the World Glaciological Monitoring Service, WGMS database), for all the glaciers with available mass balance during the considered period.

Results show that glacier albedo shows an overall decreasing trend from January 2000 on. This decline in glacier albedo is in most cases related with the annual mass balance. Trends in glacier albedo can be only partially explained by variations in air temperature suggesting that other variables as the presence of light absorbing impurities on the glacier surface could influence such trends.

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The role of national regulations in RPAS-based mapping projects in the monitoring of natural hazards that could involve infrastructure: the example of the Val Venosta Railway (Northern Italy – Bolzano)

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Keywords: national regulations, RPAS, mapping projects, monitoring, natural hazards, infrastructure.

Italy has adopted National Regulations for the use of RPAS in its country's airspace in December 2013, issued by the Italian Civil Aviation Authority (ENAC) as well as many other countries have adopted their own regulations. Despite the issued regulations, over the past months an increasing number of unauthorized and unsafe operations have been performed and the attention to safety is growing quickly in the public opinion. For this reason "Critical" operations is permitted only to those RPAS Operators which have received special authorization by ENAC after a very demanding Aeronautical procedure. According to the Regulations, the flight close to, or over congested areas, urban areas, industrial plants, highways, railway lines and stations, implies the fact that only RPAS Operators which have been authorized to the execution of "Critical" operation may legally perform such activities.

An example of a "Critical" operation were been the RPAS flights performed along the Venosta railway line to evaluate the current situation of two areas affected by geological instability and laid the basis for a future highly accurate monitoring.

In the first case the aim was to assess the upstream soil thrust on the retaining wall of the railway embankment, while in the second case the aim was to accurately reconstruct the volumes of a rock mass highly unstable.

The Venosta Valley (Vinschgau) is located in the western part of South Tyrol (Norhtern Italy – Bolzano) and is characterized by the presence of the Adige river. The valley possesses some unique features compared to the entire Alps. The first is the context particularly dry climate which results in a sharp contrast between the south-facing slope and the north-facing slope, a factor that greatly influences the distribution of vegetation. Another important feature is the presence of huge alluvional fans, which give rise to different levels of altitude in the valley and play an important role in the delineation of the longitudinal profile of the valley. From geological point of view, the Venosta Valley is characterized by the presence of the Austroalpine domain. In particular, there are two different geological units in this area: 1. The crystalline schists of the basement, which includes various complexes in which one can recognize paragneiss with interbedded amphibolite, gneiss and granitoid pegmatites, garnet micaschists intercalated with quartzites and marbles and finally phyllites, quartzites and orthogneiss; 2. The Mesozoic coverage divided into various complexes with successions of phyllites, volcanics and magmatiti, conglomerates, quartzites and dolomites. The railway line that runs through the Venosta Valley (Merano - Malles) unfolds along a path of 59,8 kilometers and covers an altitude difference of about 700 meters. In particular, three tunnel sections were made to overcome the winding first section, including the M. Giuseppe tunnel, which required extensive consolidation interventions both inside and outside.

The payload operated the camera to achieve the best images for the data acquisition and 3D model reconstruction. The flights have been conducted with manual piloting flight procedures because of the RPAS on board GPS is significantly affected by the mountain slopes proximity. For this reason, for the georeferencing procedure, ground control points have been acquired by using an high precision GPS. Flights have been performed with two different RPAS, a multicopter and an helicopter, all of them operated by a crew according to the operation risk analysis composed by three members: two pilots (Pilot in Command and Backup Pilot) operating redundant data links for flight control and a payload operator and Aeronautical Flight procedures have been applied.

In order to achieve the two aims, high precision photographic data were taken. Subsequently, using photogrammetry software, 3D models of the two areas were reconstructed with centimetric precision (pixel size 0.03 m). Starting from a 3D surface model (DSM) and using GIS 3D analysis and Raster analysis toolbox, topographic roughness was calculated and any "roughness anomaly" was checked. Moreover, RPAS data helped us to evaluate the current situation of the area affected by geological instability and laid the basis/initial situation for future high accuracy monitoring.

All the above-described activities were made according to national regulations, which make more difficult to attract business activity, especially among young entrepreneurs. Therefore, it could be simplified. However following the rules allow us to obtain a very good result in terms of safe working conditions and data quality.

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InSAR applied to tunneling: examples and recent advances

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Keywords: InSAR, Tunneling, Surface Displacement, Monitoring.

InSAR is a remote sensing technique capable of measuring ground displacement from satellite radar images. SqueeSAR™ (Ferretti et al., 2011) processes stacks of radar imagery to provide dense point clouds of high precision time series of movement for ground targets (e.g. buildings, roads, rocks, etc). InSAR is being used for monitoring tunnels during all project phases (design, excavation/construction, and operation/maintenance) in both urban and nonurban settings and is included in the "ITAtech Guidelines for Remote Measurements Monitoring Systems" (2015).

The unique characteristics of InSAR for tunneling are:

- Provide a high density of measurement points (thousands per square kilometer) over large areas without the need to install anything on the ground surface
- Provide baseline studies of ground deformation prior to construction using archive satellite imagery
- Identify and monitor residual deformation after tunnel completion

Two examples of InSAR data applied to tunnelling projects are presented.

In the first case, a railway tunnel was constructed in an urban area, which caused unexpected and extensive surface displacement along the corridor. Buildings above the tunnel were significantly damaged and some were evacuated for site remediation. A post-incident SqueeSAR™ analysis characterized the settlements and supported the design of the remedial work.

In the second case, a highway tunnel excavated under a quiescent landslides was monitored with SqueeSAR™ and conventional techniques (inclinometers, piezometers and total stations). SqueeSAR™ analyses with different satellites, covering the period from March 2003 to March 2015, provided displacement data prior, during and after the tunnel excavation. The tunnel excavation (January 2011 to March 2013) triggered a landslide reactivation. InSAR data supported the back-analysis, through advanced three-dimensional modelling of the interaction of tunnel excavation and deep-seated landslides, and provided a unique tool to verify and calibrate conventional monitoring data.

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Integrated analysis of DInSAR and buildings damage data for preliminary vulnerability assessment of urban settlements affected by slow-moving landslides

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Keywords: slow-moving landslides, vulnerability, building damages, Differential SAR Interferometry.

Several urban settings have developed in unstable areas, especially in recent times. For this reason, a considerable interest towards innovative approaches useful to provide information on temporal and spatial phenomena evolution and on their interaction with existing buildings has grown among the scientific community and land management institutions. The present work suggests a new methodology which can be used, on one hand, to update the available landslide inventory maps, and, on the other, to assess at a preliminary stage the vulnerability of structures within slow-moving landslides affected areas. Such procedure consists of an integrated analisys combining landslides kinematic assessment and buildings' preliminary survey. For the latter purpose, after classifying buildings in terms of homogeneous structural types, a vulnerability matrix is defined, which combines landslide intensity and building damage severity, and thus provides information about structural instability likelihood due to ground movements. In order to define landslide intensity and also to update activity maps, geological field survey and conventional in situ measurements (where available), integrated with mean velocity of displacement obtained by remote sensing techniques such as Differential Interferometry SAR (DInSAR), were performed. Moreover, the combination of interferometric data, acquired along "ascending" and "descending" tracks, allows to identify the predominant movement direction and its vertical and horizontal components. The structural survey of building damage can be performed using several classifications available in literature (e.g. Boscardin & Cording, 1989, Iovine & Parise, 2002). The proposed methodology has been here applied for the urban settlement of Gorga, belonging to the Stio municipality (Salerno province). Gorga's geological setting is mostly characterized by limestones and marly-sandy units, belonging to the Saraceno Formation (Eocene – Miocene in age). The whole territory is affected by several landslides: in detail, according to Hydro-geomorphological Setting Plan (HSP - South Campania River Basin Authority, 2012), a Deep-Seated Gravitational Slope Deformation (DSGSD), flows and complex landslides can be recognized. DInSAR analyses were performed on COSMO-SkyMed datasets, acquired in the time-span 2011-2014, and processed by Coherent Pixel Technique (CPT, Mora et al., 2003) algorithm, while damage assessment is carried out through Iovine & Parise classification. The proposed vulnerability matrix turned out to be particularly suitable for medium-scale analyses, allowing to obtain a zoning map with different vulnerability rates, which, in turn, could be a useful tool for the identification of the most critical areas. Such areas require more detailed and quantitative analyses in order to define, through displacement time series obtained by DInSAR data, future conditions of damage and local failures of specific buildings and building aggregates.

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Radar interferometry from space for the investigation of surface deformations: 25 years of observations and technological developments

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Keywords: Differential Synthetic Aperture Radar Interferometry (DInSAR), ERS-1/2, ENVISAT, COSMO-SkyMed.

The space-borne Differential Synthetic Aperture Radar Interferometry (DInSAR) techniques have continuously evolved over the last 25 years, becoming an important "tool" for the investigation of Earth surface deformation, as well as for buildings and infrastructures monitoring. Indeed, these techniques are widely exploited both for studying the deformation phenomena relevant to natural events (i.e. earthquakes, volcanic activities, landslides) and for analyzing displacements due to anthropogenic actions, such as underground resources exploitation.

Originally, the DInSAR methodology has been successfully applied to analyze single deformation episodes thanks to its capability to generate spatially dense deformation maps of large areas, with centimeter to millimeter accuracy. However, benefiting from the availability of large SAR data archives, the interest of the scientific community has progressively moved towards the study of the temporal evolution of the detected displacements. To do this, advanced DInSAR techniques have been developed, allowing the computation of deformation time series from multi-temporal sequences of SAR images relevant to the areas of interest.

The space-borne DInSAR scenario is currently characterized by the huge availability of SAR data acquired over the last 25 years; they include the long-term C-band ESA archives (e.g. ERS-1/2 and ENVISAT), the RADARSAT-1/2 data sequences, the data provided by the L-band ALOS-1 system and those acquired by the X-band new generation SAR sensors, such as the COSMO-SkyMed (CSK) and TerraSAR-X (TSX) constellations. Moreover, a massive and ever increasing data flow is going to be further supplied by the recent Sentinel-1 SAR satellites (Sentinel-1A has been launched on 2014 and, on April 2016, it has been paired with the Sentinel-1B twin system) operating within the framework of the COPERNICUS (formerly GMES) Programme of the European Union. This two-satellite constellation shows enhanced revisit and coverage performance, with a ground footprint of about 250 km and an orbit revisit time of 6 days. Accordingly, new Big Data archives relevant to extended areas on Earth will be soon available, acquired with a SAR mode specifically devoted to Advanced DInSAR applications and in a "free and open access" data scenario.

This contribution will first introduce the basic concepts of the DInSAR methodology and then will move to the presentation of the advanced DInSAR techniques. Several results, achieved through the exploitation of SAR data relevant to the different sensors characterizing the current DInSAR scenario, will be shown. In particular, the discussion will start with the first generation SAR satellites, such as the ERS-1/2 and ENVISAT sensors, to conclude with the investigation of the more recent ones, e.g. the Sentinel-1A/B systems, highlighting the significant improvements of the achieved deformation mapping capabilities.

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On the monitoring bridge by sperimental tromography

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Keywords: HVSR technique, Seismic hazard, resonance frequency, Southern Italy.

The test passive seismic single station detects the frequencies at which the motion of the ground is amplified by resonance stratigraphic. The test is commonly referred to as evidence "HVSR" or simply "H / V" means the ratio between the spectral components horizontal (H) and the spectral component vertical (V). The method used in this study to estimate the frequency of oscillation of the structure is as follows: analysis of HVSR (Horizontal to Vertical Spectral Ratio) relations. This allows for evaluation of very simple oscillation frequencies for land and structures. The tool used for data acquisition is an experimental digital tromograph. As the ground, excited by the waves that pass through it, has more vibration modes also the structures and buildings in the c.a. They have in turn the resonance frequency of the building. It 's hould avoid the phenomena of double resonance that is, those cases in which the natural frequency of the terrain has peaks with resonance frequencies similar to those of the building. This technique is aimed to study the dynamic behavior of bridges in the province of Cosenza, in southern Italy, and understand the frequency of these structures to see if their earthquake resistance.

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The updated scenario in Europe of Natural Hazards Vs UNESCO Cultural heritage: the PROTHEGO approach

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Keywords: Geo-hazards, UNESCO, PROTHEGO, Remote Sensing.

The present paper has been implemented as a part of the PROTHEGO project. The project was funded through the JPI on Cultural Heritage and Global Change program, under ERA-NET+ and the FP7 Programme of the European Commission. PROTHEGO is coordinated by ISPRA with the support of the Natural Environment Research Council (NERC, UK), the Milano Bicocca University, the Cyprus University of Technology (CUT) and the Instituto Geológico y Minero de España. The project aims to make an innovative contribution concerning the analysis of geo-hazards in areas of cultural heritage in continental Europe through remote sensing and satellite techniques. The main object of the research is to analyse the state of the art of UNESCO World Heritage List (WHL) sites and geo-hazards distribution at European scale. All European sites of the UNESCO WHL have been analysed in terms of potential causative factors and triggering mechanisms, acting in the surrounding of each cultural heritage site. In order to provide an updated overview, a detailed analysis of available datasets concerning the distribution of UNESCO WHL Cultural Heritage (CH) sites and geo-hazards in Europe has been implemented. To this end, a specific web geo-database was designed and developed. In order to achieve this target all the UNESCO European World Heritage sites were collected and elaborated in digital form. For each site, if not available, polygons of the core and buffer zone were digitalized. The obtained database contains at list four hundred sites with more than 2500 polygons, classified as cultural, natural or mixed. Moreover the appropriate available databases concerning natural hazards in Europe were collected and investigated for a preliminary spatial analysis in order to produce a first overview of UNESCO European Heritage at risk. The following hazards have been take into account: seismic through the SHARE project output, landslide with ELSUS susceptibility map, subsidence and volcanic hazard. For completeness also the flood hazard, with the support of the flood directive output, has been considered. Italy seems to be one of the most critical country due to the largest number of CH sites (51) and the contemporary presence of several types of natural hazard affecting its territory. In this work such information has been highlighted in order to address future efforts of international scientific community for Cultural Heritage conservation, alongside the specific contribution that PROTHEGO project outputs will play to fill these gaps. The final outcomes of this research will allow to identify gaps and needs at European scale.

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A multidisciplinary and multispectral approach to characterise the Corfinio archeological site (AQ)

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Keywords: multispectral imaging, NDVI, data fusion, landscape archaeology.

Remote and proximal sensing techniques are able to strongly support the archaeological research in terms of regional to local scale studies. The development of the so-called landscape archaeology has to include remote sensing analyses to better understand the context where ancient settlements developed. Contextual studies of the landscape can be accomplished via both morphometric analyses using Digital Elevation Models (DEMs) and estimates of the ancient land cover distribution using multispectral sensors. Alongside the regional investigation, the archaeological research requires information about the underground - where possible ancient structures can occur - to be acquired. Underground studies are accomplished using geophysical investigation techniques, like GPR (Ground Penetrating Radar) and a tridimensional ERT (Electrical Resistivity Tomography), which are generally carried out for geological investigations and, being non-invasive, are suitable for the investigation of possible buried features.

We used such a multidisciplinary approach to study the landscape archaeology in the central part of the Abruzzo region (Italy) with detailed underground investigations of the Corfinium settlement in the proximity of the "Valvense Abbey" (XI-XII sec.). The aim of the research is to: a) provide a regional context to archaeological studies in the Corfinium site, and b) unravel the complicate asset of the Corfinium site which has been populated several time in ancient periods.

In order to accomplish these main objectives we used: a) remote sensing techniques for the extraction of morphometric features and land use estimates; b) geophysical techniques to identify buried structures.

The remote sensing analyses was carried out with aerial multispectral data available from Regione Abruzzo in 2011 and a dedicated flight performed by Guardia Costiera - Nucleo di Pescara equipped with the ATM-Daedalus in 2014. A 3D model was also obtained LIDAR data as well as by drone imaging. Some interesting features were identified using a stretched NDVI processing tool, though this area is strongly modified by agriculture activities which alter the potential response of buried remnants. These results were in agreement with the subsurface response depicted by the geophysical investigation and open new views about the archeological evolution of this intriguing site.

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Application of Persistent Scatterer Pair (PSP) – SAR interferometry data: velocity and acceleration annual rates (1993–2010) in Campi Flegrei, Italy

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Keywords: SAR, differential interferometry, PSP, ground deformation, Campi Flegrei, Italy.

Campi Flegrei is an active volcanic district located along the Eastern Tyrrhenian continental margin, southern Italy, and is worldwide known for dramatic ground deformation phenomena (bradyseism) recorded over the last centuries. Our purpose is to present detailed Campi Flegrei maps of annual rates of ground deformation fields (average velocity, average acceleration, and combined annual velocity/acceleration), referred to almost two decades (years 1993–2010). The research (Iuliano et al., 2015) was based on a temporal analysis and advanced mapping of Persistent Scatterer Pair (PSP) data, obtained from interferometric processing of radar satellite European Remote Sensing (ERS)-1/2 and Environmental Satellite (ENVISAT) scenes of the study area. Patterns and trends of annual PSP velocity have provided a reconstruction of the spatial and temporal variability of ground deformation in terms of uplift and/or subsidence along the satellite line of sight (LOS). The analysis of annual PSP velocity and acceleration has revealed an intense and variable dynamics of the Campi Flegrei caldera collapse-resurgence system, testified by the high PSP velocity and acceleration values, as well as the significant changes in the rates of ground deformation through time. The main results of this research indicate that the largest ground deformation is localized within and around the structural border of the Campi Flegrei caldera and suggest a systematic recurrence of opposite trends (uplift vs. subsidence) in the ground deformation of the inner caldera region with respect to the surrounding areas throughout the analyzed time period.

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Subsidence zonation through satellite interferometry in coastal plain environments of NE Italy: a possible tool for geomorphological and geological mapping in coastal plain environments

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Keywords: PS-DInSAR, land subsidence, Quaternary deposits, Venetian-Friulan Plain.

In the coastal areas the recent sedimentation buries the previous deposits that often can be rather different from surface formations. A similar situation is sometime common also in the urbanized zones and these settings frequently hamper the correct assessment of the subsoil, even of the first 5-30 m. With the aim of reconstructing the shallow stratigraphic architecture, this work analyzes the possible relationship between the geological and geomorphological features of a coastal plain and the rate of subsidence. In this perspective the Differential Interferometry Synthetic Aperture Radar (DInSAR) could be used as a tool for geomorphological and geological mapping. This work is focused on a coastal sector of the Venetian-Friulian Plain between Portogruaro and Concordia Sagittaria, upstream of Caorle Lagoon. In the last 125 kyr this area experienced an average downlift rate of about 0.4-0.5 mm/yr, related to crustal flexuring and sediment compaction (Antonioli et al., 2009). But the on-going subsidence is considerably faster, probably related to the reclamation of the 19-20th centuries and current groundwater withdrawal. The studied plain was formed by the interplay between the fluvial system of Tagliamento River and lagoon and marine environments. During Lateglacial and early Holocene (19-8 kyr BP), Tagliamento River eroded several incised fluvial valleys, with a maximum depth of 15-25 m and a width of 500-2000 m. These features entrenched in the alluvial sediments of the Last Glacial Maximum (LGM) but, since about 8 kyr BP, the coastal and deltaic processes favored their filling with lagoon and alluvial sediments (Fontana, 2006; Amorosi et al., 2008). Downstream of Portogruaro the incisions have been completely buried by younger deposits and their detection is now possible only through subsoil investigations (Fontana et al., 2014).The sediments filling the post-LGM incisions are prone to a higher consolidation, especially if compared to the external plain. This characteristic allows to recognize and map the boundaries of the incisions, even where they are no more evident at surface, through the assessment of a different rate of downlift. To detect the subsidence patterns of this area, we considered the Time Series of surface displacement produced by PS-InSAR analysis of ERS, ENVISAT and SENTINEL data referred to the periods 1992-2000, 2003-2010 and 2014-2016, respectively. Results show that the subsidence rate is 3÷8 mm/yr (in some points over 10 mm/yr), in the post-LGM incision filled by lagoon and alluvial sediments, whereas they decrease to 0.5÷3 mm/yr where LGM surface crops out. The investigated zone represents a good test site to check the correspondence between surface displacements, obtained through interferometric data, and geological information because Holocene and Pleistocene deposits are affected by an evident variation of subsidence and a huge database of stratigraphic cores and geotechnical tests is available for this area.

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Active faults and ground deformation in the southern Matese area (Campania region)

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Keywords: southern Apennines, active faults, tectonic geomorphology, remote sensing, PS-InSAR.

Combined satellite interferometry data (remote sensing) and tectonic geomorphology analyses have been carried out with the aim of providing new constraints to the recent/current tectonic framework of one of the most seismically active regions in the southern Apennines. The study area includes the southern Matese ridge and adjacent Alife Quaternary basin, and falls in the epicentral area of the Ml = 4.9, 2013 earthquake. Satellite interferometry data are based on phase comparison of SAR images acquired at different times and perspective views. Permanent Scatterers Interferometric Synthetic Aperture Radar (PS-InSAR; Ferretti et al., 2001) is one of the latest applications of SAR time series data analysis. Permanent Scatterers are radar image points on the ground, which show stable interferometric phase behaviour for wide look-angle variations over time. Therefore, PS can be used to estimate the progressive sub-vertical motion of the ground surface, and from geostatistical spatial analysis of PS-InSAR data can be derived deformation maps. In this study, we have used satellite interferometry data spanning over a long - 20 year -time span, i.e. PS datasets by ERS 1 + 2 (1992 - 2000) and ENVISAT (2002 - 2010), obtained by Ministero dell'Ambiente, della Tutela del Territorio e del Mare (MATTM), and by RADARSAT 1 (2003 - 2008, of the Regione Campania Administration). The datasets have been analysed through a GIS software by a clustering geostatistical methodology, which allows identifying clusters of kinematically homogeneous PS with reference to mean PS velocity values. The spatial analysis identifies statistically significant elements using the Anselin Local Moran's I statistic. The calculated indexes show whether the apparent similarity (spatial clustering of high/low values) or dissimilarity (spatial outliers) is more pronounced than one would expect in a random distribution. According to Perrone et al. (2013), interpretation of single kinematic domains and boundaries between kinematic clusters is based on integration with geological information.The tectonic geomorphology study, which has been carried out through the analysis of detail-scale topography data and field data, has allowed identifying several faults that have been active during the late Quaternary. The satellite interferometric data analysis points to the presence of distinct kinematic domains in the study area. Both the deformation pattern, and the boundaries between single kinematic domains are consistent with tectonic geomorphology evidence. Overall information indicates that some of the structures that have produced offsets during the late Quaternary are active, and control current deformation in the study area.

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Contribution of remote sensing to landslide integrated monitoring system: the use of ground-based SAR interferometry in Austrian Alps

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Keywords: Landslide monitoring, Rockfall, GB-InSAR.

In mountainous regions, such as alps, rockfalls are one of the most common geomorphological processes representing one of major causes of landslide fatalities and economic losses. According to GEORIOS database (GEORIsiken ÖSterreich), in Austria more than 30,000 gravitational mass movements have been counted, 19% of which are rock falls. In this context, the monitoring of parameters concerning triggering factors (eg. temperature, rainfall, pore pressure) and displacement (deep and shallow), plays a key role in the preparation of actions for risk reduction. The present work illustrates the integrated monitoring system of Ingelsberg in Bad Hofgastein, where a highly hazardous landslide in Salzburg Land is located. A 15-months monitoring campaign (March 2013 – July 2014) was realized through the use of several monitoring instrumentations such as 5 bar extensometers, 2 weather stations and 3 cameras (Romeo et al., 2014). In this framework, it was also carried out an accurate monitoring of the surface displacement, with high temporal and spatial resolution, by using terrestrial SAR interferometry technique, constituting the first long-term GB-InSAR (Groung-Based Interferometric Synthetic Aperture Radar) measurements implemented in Austria.

During the monitoring campaign, a main rockfall occurred at the end of April 2013 that involved up to 40 m3 of rocks. Thanks to the large amount of data, it was possible to analyze the pre-failure days in order to detect possible factors that contributed to the collapse: surface displacement given by GB-InSAR was compared with displacement measurements in depth given by extensometers and results are discussed taking into account meteorological conditions antecedent the rockfall triggering.

The integration between conventional monitoring methods and new technologies such as GB-InSAR was very useful for the comprehension of landslide processes, particularly in rock slope where, for example, by comparing displacement time series with other parameters as temperature and rainfalls, it is possible to identify the most susceptible blocks to collapse (Mazzanti, 2014). In addition, a multi-instrumental approach is essential to investigate movements both in surface and in depth and the use of different monitoring techniques allows to perform a cross analysis of the data, to check the data quality enhancing the reliability of the entire system. This is of paramount significance in early warning systems.

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Mapping of biogenic soil crusts based on innovative remote sensing methods

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Keywords: Biogenic soil crust, erosion, satellite, mapping, fluorescence.

Biogenic soil crusts (BSCs) play an important role in preserving soil surface from wind and water erosion in many arid and semi-arid areas of the planet. Monitoring the spatial and temporal changes in BSC distribution and conservation status provides highly valuable information on soil surface stabilization and their evolution related to climate changes in arid environments. In this contribution, we examine the potential of new remotely sensed indices for mapping the spatial distribution and activity of BSCs. Different compositions of BSCs, i.e. cyanobacterial crusts, moss crusts and lichen crusts were sampled along a rainfall gradient of the Negev Desert where annual average precipitation ranges from 325 to 50 nm. Soil crust optical properties were measured by means of high resolution spectroradiometers under direct solar irradiance. Different optical vegetation indices (NDVI – normalized difference vegetation index, MTCI – MERIS terrestrial chlorophyll index and PRI – photochemical reflectance index) were calculated. As a new remote sensing approach, we also quantified the sun-induced chlorophyll fluorescence emission, which has two emission peaks in the red and far-red spectral regions. The preliminary results showed that, immediately after watering, the ratio between the red and far-red fluorescence peaks of BSCs becomes and stays very well distinct from that of higher plants (e.g. shrubs and herbs). Such a distinctive fluorescence pattern is expected to open new opportunities to identify active BSCs from airborne and satellite data and to monitor their activity over time to improve the mapping of soil vulnerability to wind and water erosion. This result is particularly interesting in view of the European Space Agency Sentinel missions that provide repeated high resolution satellite images and of the upcoming FLuorescence EXplorer mission (8th Earth-Explorer Satellite mission selected in November 2015) specifically aimed at detecting and measuring fluorescence from space. The potential of coupling optical and thermal satellite data to investigate the spatial distribution of BSCs will be also discussed.

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The application of modern technologies of Geomatics in the Engineering Geology

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Keywords: Geomatics, engineering geology, remote sensing, digital photogrammetry, laser scanning, remotely.

The Geomatics, also known as geospatial technology or geomatics engineering, refers to the set of disciplines that deal to gather, interpret, process, model, store and deliver geographic information. The Geomatics, among the others, includes tools and techniques referable to land surveying and positioning (i.e. topography, Global-Navigation Satellite Systems - GNSS), satellite, aerial and ground-based remote sensing (i.e. digital photogrammetry, laser scanning, Remotely Piloted Aircraft System - RPAS), Geographic Information Systems (GIS), digital mapping and geostatistics. In recent decades, thanks to technological advances, these tools have been increasingly spread and used in the study of geological hazard and risk. In fact, these techniques provide innovative tools not only in supporting cartographic products but also in the analysis and the quantitative measurement of geological processes located in inaccessible areas at different scales. Nowadays, it is possible to remotely collect a deterministic series of data which characterizes in detail the structural geological setting and the geomorphology of a studied area. Applications of engineering geology, as for example the hydro-geological risk assessment, the rock fall runout modelling, or the slope stability analysis, can have a great benefit by the use of remote sensing data based on satellite platforms, aircrafts and RPAS. Many currently operational missions (i.e. optical, multispectral, SAR), as well as ground-based methodologies (i.e. total station, laser scanning, IR thermography) continue their widespread use, as proved by the increasing number of scientific papers based on such applications. Recently, mobile terrestrial laser scanning is emerging as a remote data collection technique capable of generating accurate fully three-dimensional virtual models while moving at different speeds. During the presentation, the processes of extraction of topographic and geothematic information will be shown and the development of additional methods for producing spatial data containing numerical information with a multi-temporal nature presented. Examples of processing of satellite imagery and photos, both from aircraft and RPAS, will be shown in association with 3D data for the production of digital models to be used in the extraction of engineering geological information. The theoretical fundamentals of the involved disciplines will be also re-called and case histories of geological events related to the national territory shown.

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Remote sensing techniques in underground mining: Application of terrestrial LIDAR for stability analysis and optimization of excavation activities

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Keywords: Terrestrial LiDAR, underground mining, stability analysis, marble, numerical modelling.

A detailed knowledge of the structural setting of a rock mass is essential for proper planning of safe underground excavation activities. Terrestrial LiDAR technology can allow detailed remote data acquisition not only for determination of mine rock face geometry but also for evaluation of the spatial characteristics of discontinuities. This remote data collection can be combined with traditional engineering-geological surveys for deterministic mapping of the discontinuity sets to be used in subsequent stability analysis (Francioni et. al, 2014). In addition, tunnel excavation changes the pre-existing stress state, which can induce brittle deformations that may lead to instability in the excavation walls and a reduction of the quality of the extracted material. It is therefore very important to consider changes over time in stress orientation and stress magnitude in the mining area; these are influenced by both new tunnel excavations and by the presence of discontinuities, especially within a competent marble rock mass.

This case study provides an example of a working approach that combines terrestrial LiDAR and traditional geological surveys for engineering-geological investigations. A three-dimensional model (Vanneschi et al., 2014), which includes information about the geological structures in an underground marble mine in the Apuan Alps, is combined with information about discontinuities identified and mapped in a deterministic way by using the LeicaTM TruView plug-in, which manages laser scanning data plus high definition images and allows georeferenced representation of the fractures. After GIS processing and additional in situ engineering-geological surveys, data was used to create a 3D virtual reality illustrating the deterministic fracture pattern and properties of the single discontinuities. The detailed documentation of the geomechanical and geostructural characteristics of the discontinuities was subsequently used to perform numerical modelling analyses, to provide further insight into likely stress conditions. The results of the investigation can be used to improve optimization of the excavation activities, taking in consideration the effects of local variation of the stress which is primarily reflected in situ by observed fracturing.

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Isostatic rebound between the riverbanks and the discharge of the Po River (northern Italy) by wavelet coherence analysis of high-resolution remote sensing and discharge data

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Keywords: ground vertical movement, satellite data, climate data, Po Delta.

Land movements cause changes in topographic gradients which could favor flooding of urban, agricultural or coastal areas. Moreover, sea level rise linked to recent climate changes has increased awareness that the ground deformation, although slow over time, can become hazardous both for humans and environment. The understanding of the causes of land movements is a not easy task due to the complex relation between natural and anthropic mechanisms. In order to improve the knowledge of natural versus anthropogenic variability of vertical land movements of the Po River Delta (northern Italy), in this work advanced data analysis techniques were used for finding possible correlations between high-resolution remote sensing data and river discharge records. In particular, focus was placed on the isostatic rebound between the river banks and the discharge of the Po River within its Delta area. Daily ground deformation measurements obtained with Continuous Global Positioning System (CGPS) were used, referring to the stations of Porto Tolle (44°57'07.2"N - 12°20'02.4"E) and Taglio di Po (45°00'10.8"N - 12°13'40.8"E) between 2012 and 2015, and the daily Po River discharge record at Pontelagoscuro (44°53'19.68"N - 11°36'29.52"E).

It has been found that the vertical displacement functions between the two river bank stations, which are located at about 10 km apart, are strongly correlated. This suggests that the Po riverbanks in this area could be characterized by similar dynamics. On average, CGPS measurements indicate a downward movement of about 4 mm/yr. The use of cross wavelet and wavelet coherence analysis between the CGPS data and the Po River discharge data put in evidence that these records present strong negative correlation between 3- to 12-month scales. In particular, three main correlated frequency ranges with periods of 3 months, 4 - 6 months and 8 - 14 months were identified. These ranges correspond to the seasonal, semiannual and annual natural meteorological variations observed in the entire Po River area. The found negative correlations indicate that the increase/decrease of the river discharge induces the simultaneous decrease/increase of the near riverbank. The observed oscillations have an amplitude of a few millimeters (at most 5 mm). A possible cause of this regular seasonal oscillating movement could be an isostatic rebound of the riverbank in response to the change of water pressure on the river bed, which is directly related to the river discharge volume.

SESSION S27

Mapping, monitoring and modeling: tools for landslide hazard assessment

CONVENERS AND CHAIRPERSONS

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Statistical analysis of long-term displacement rate for definition of Early Warning thresholds applied to case studies of the Ruinon and Mont de La Saxe landslides (Northern Italy)

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Keywords: Landslide Rockslide Early Warning Monitoring TLS SAR EWD La Saxe.

Large rockslides are characterized by complex spatial and temporal evolution, in addition to non-linear displacement trends and the significant effects of seasonal or occasional events on their behaviour. The displacement rate and the landslide evolution are intensely influenced by many factors like lithology, structural and hydrological settings, other than meteorological and climatic factors (e.g. snowmelt and rainfall). The relationship among these factors is evidently non-linear and site specific for each sector within the main landslide mass.

Different Early Warning domains (EWD), characterized by different velocity regimes (slow to fast domains) and with different sensitivity to external perturbations (e.g. snowmelt and rainfall), have been identified in previous studies at the two sites.

In this work, total displacement and displacement rate time series are extracted from Ground-based Interferometric synthetic aperture radar (GB-InSAR) surveys, monitoring of optical targets by total stations, a GPS network and multi-parametric borehole probes and from DEM difference (calculated by various algorithms) derived from terrestrial laser scanner surveys.

The Mont de La Saxe rockslide (ca. 8 x 10^6 m^3) is located in the Upper Aosta Valley (Crosta et al., 2014), and it has been intensely monitored since 2009 by the Valle D'Aosta Geological Survey and have been subdivided into 5 EWD. The Ruinon landslide (ca. 15 x 10^6 to 20 x 10^6 m^3) is located in the Upper Valtellina (Lombardy region) and monitoring data are available starting since 2006 (provided by ARPA Lombardia) and subdivided into 8 EWD (Crosta et al., 2016).

Both sites are located within an alpine deep-seated rock slope deformation characterized by dissimilar displacement velocity, from centimetres to meters per year, and which have undergone exceptional accelerations during specific events.

We experiment the use of normal probability plots for the analysis of displacement rate data of each point belonging to different landslide sectors and recorded during almost ten years of monitoring. These analyses allow us to define: (i) values with a specific probability value expressed in terms of percentiles; (ii) values for which a specific change in behaviour is observed which could be associated to a specific type of triggering event (e.g. rainfall intensity, duration or amount; snowmelt amount). These values could be used to support the choice of threshold values for the management of Early Warning System, by considering also the minimization of false alarms.

The analyses have been performed using data averaged with different time intervals so to study the effects of noise on the threshold values. Analyses of false alarm triggered by the choice of different threshold values (i.e. different percentiles) have been implemented and analysed.

Finally, cross-correlation has been used to discriminate the different areas.

This could represent an innovative approach to define velocity thresholds of Early Warning system and to analyse quantitative data derived from remote sensing monitoring and field surveys, by linking them to both spatial and temporal changes.

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Monitoring of a fast moving landslide in a weak cemented sandstones in the Northern Apennines

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Keywords: Flow type landslide, weak sandstones, monitoring, Northern Apennines.

Landslides of the flow type are known to cause severe damages to houses and infrastructure (e.g. Hungr et al., 2001). Despite numerous documented cases of landslides that evolved from moderately to fast moving flow like landslides, the mechanics involved in this transition remains still uninvestigated (van Asch and Malet, 2009). This is also due to the difficulties in designing a monitoring system that registers this transition with high frequency data. We present in this work a case study of a first time failure in a bedded sandstone in the Northern Apennines of Italy. The landslide is referred to throughout the work as Ronco-Puzzola landslide, which is located in the municipality of Grizzana Morandi, approximately 30km S of Bologna in the Northern Apennines of Italy. The landslide evolved in two distinct stages: the initial failure took place on April 2013 and the catastrophic reactivation occurred on 10th February 2014. In according to Cruden and Varnes (1996), the Ronco-Puzzola landslide can be classified as composite rock-earth slide in the upper part of the slope with flow like cinematic in the lower portion. Surface geophysical analyses were carried out in order to define the consistence and volumes of the involved material. In detail, periodic ReMi-MASW surveys and HVSR acquisitions were performed both inside and outside the landslide body to define the pre and post-event slope condition. A monitoring system was installed on October 2013 in the upper portion of the landslide and it consisted of 2 piezometers equipped with electric pressure transducers, 3 inclinometers, 3 wire extensometers and 12 visual targets mounted on steel rods. At the time of slope failure (Feb. 10th, 2014), only the visual targets, the pluviometer and a piezometer were active. According to the extensometer data, the upper part of the landslide started to move steadily by 1mm/day since the beginning of December 2013. On January 19th, 2014 all the visual targets started to move: the highest velocities were recorder from the lower and central targets (1800mm/day), whose data are available only until Feb. 2nd, because the landslide swamped one of the target. Sudden increases in displacement rates were observed between Jan. 30th and Feb. 1st (500 mm/day) and at the catastrophic failure (400mm/day). Although different parts of the landslide mass moved synchronically, at this stage the velocities are slightly higher for the targets placed in the upper part. Rapid increases of displacement rates are closely associated with short precipitation inputs. The second stage of the monitoring system activity began on July 2nd 2014: the rate of displacement recorded after mitigation measures were undertaken, indicates that the landslide is substantially stable and the water table level lies on average at 4.5m below the ground level.

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Preliminary results of continuous monitoring of a slope with clayey soils prone to shallow landslides

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Keywords: Landslides, soil geotechnical characterization.

Rainfall-induced shallow landslides are one of the most common type of landslides of the entire world. Besides the limited volume of soil mobilized by these phenomena, they can provoke serious damages to cultivations, infrastructures and buildings due to their high speed of development and their high density in small areas.

Shallow landslides triggering is strictly linked with the hydrological and mechanical responses of a usually unsaturated soil to rainfalls. When these phenomena occur in clayey soils, hydro-mechanical behaviors are more complex because of other different physico-chemical processes affecting soil shear strength, such as softening caused by repeated cycles of shrinking-swelling.

Thus, to identify the physical and hydrological conditions leading to landslide triggering, a continuous monitoring of unsaturated soil is needed, in particular related to the change in soil hydrological properties related to different rainy or dry periods. This becomes fundamental also for correctly modeling slope safety factor.

In this work, the preliminary results of the continuous monitoring of a slope prone to shallow landslides with clayey soils are presented. The test-site is located in Ardivestra catchment (central Oltrepò Pavese, northern Apennines, north-western Italy). It was affected by several shallow failures in the years 2009-2014.

The main aims of this work were: i) to characterize the slope soils by a multidisciplinary point of view; ii) to identify the main soil hydrological behaviors; iii) to recognize the processes and the mechanisms which could promote the triggering of shallow landslide.

The test-site soils were characterized by a multidisciplinary point of view, for identifying the features that can influence the soil hydro-mechanical behavior. Soil geotechnical characterization allowed to measure the physical parameters (grain size distribution, Atterberg Limits, volumetric index properties), the shear strength (direct shear tests, oedometric tests), the shrinking-swelling potential. Hydrological characterization determined the water retention and hydraulic conductivity properties. Pedological and mineralogical characterizations were also carried out.

Field monitoring allowed to identify the soil hydrological behaviors, linked to different meteorological conditions. The station integrated field devices for measuring soil hydrological parameters (water content, pore water pressure, water electrical conductivity) at different depths, with data of rainfall, air temperature, wind speed and direction. The monitoring period has started in November 2015.

These results allowed also for recognizing the predisposing factors and the hydro-mechanical conditions that can lead to trigger shallow landslides. Moreover, these analyses provided important indications for the correct application of slope stability models in slopes with clayey soils.

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A dissertation on the stability conditions of the Sorrento-Amalfi Peninsula: lessons learned from 50 years of research and future perspectives

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Keywords: Landslide mapping, landslide susceptibility, Sorrento-Amalfi Peninsula.

The 50-year-long research activity on the slope stability of the Sorrento-Amalfi Peninsula, an area considered as one of the most prone to landslide and flooding risk of Campania, carried out by the School of Engineering Geology of the "Federico II" University is summarized by more than 100 scientific papers. The papers detail several topics including geological, geomorphological, and geostructural features as well as landslide-triggering factors, geotechnical characteristics, hydrogeology, hydrology and anthropic impacts. Although the pioneering studies performed in the '60s were mainly based on the geological and geomorphological setting, they were the first to point out the relevant role of the pyroclastic soils in triggering flow-type landslides. Afterwards, the researches focused on triggering factors and propagation of debris flows, rockfalls and slow moving-landslides, in order to define the most likely invasion zones. Furthermore, other studies in the area dealt with karst and the rainfall analyses, which strongly contributed to the hydrogeological risk. In this synthetic overview, it is also relevant to mention the activities carried out on the territory by the local stakeholders ("*Autorità di Bacino*"), which were directly involved in the assessment of the susceptibility and risk areas by the n° 183/1989 and n° 180/1998 laws. More recently, the Civil Protection School of the Campania Region enhanced the former studies by identifying more than 500 warning hotspots. The experience coming from more than 50 years of research coupled with the most innovative investigation techniques provided an updated hazard scenario for the entire Sorrento-Amalfi Peninsula, which represents the benchmark for managing the future challenges, such as the projected climate changes which are exhibiting an increase in the frequency of flash floods.

This paper is dedicated to the memory of the Professors and Colleagues who worked before us with the most sincere acknowledgement for the passion and enthusiasm that they lavished on their research.

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Benchmark test of a GNSS low-cost, single-frequency, geodetic monitoring system

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Keywords: GNSS low-cost monitoring system.

Ground displacements caused by gravitational slope deformations, landslides, subsidence, bradyseism or volcanic activity can lead to damages of buildings and infrastructures and often to a significant increase in the probability of human lives and economic losses.

GNSS technology has been widely used for spatial reference system definition and the deformation monitoring of tectonic processes in wide regions. Actually the main drawback is related to the high cost per unit (>10.000 Euros average) which limits the spread of such systems in small-scale areas and their use for local geophysical surveys.

Within the R&D project SIMULATOR (co-funded by Regione Lombardia - POR FESR 207-2013) the Geomatics Division of Esri Italia investigated the possibility of using “low-end” GNSS receivers in order to achieve adequate performance for an effective monitoring of surface deformations. The research activity demonstrated how these devices allow to obtain sub-centimeter level repeatability with static-differential processing in case of local networks (baselines up to 10 km), even when using low-cost receivers as reference. The outcome of the research, engineered together with SpaceExe, a startup specialized in the design of integrated GNSS devices, brought to the realization of a commercial solution named SENDAS (SurfacE Network Deformation Analysis System), an autonomous and continuous static monitoring system based on low-cost GNSS receivers. SENDAS is based on a network of GNSS permanent stations using the UBLOX M8T L1 chipset, optimizing weight, dimensions, cost and power supply. A dedicated gateway remotely transmits raw GNSS observables to a server and computes the relative displacements of the network points.

This system has already been deployed on two Italian landslide sites (one in collaboration with Comunità Montana Valtellina and one with Istituto Nazionale di Oceanografia e Geofisica Sperimentale di Trieste) and will soon be installed on a natural gas storage site managed by Edison SpA, one of the Europe’s oldest energy company and one of the industry leaders in Italy and Europe.

In order to assess the performance of the survey system four SENDAS stations have been deployed by INGV (Istituto Nazionale di Geofisica e Vulcanologia) on a slope deformation near Fiastra, Macerata (Central Apennines). During a 8 month time span the performances of the SENDAS system, in term of repeatability and regressions slope, have been compared to results obtained by co-located geodetic grade receivers. In this paper the characteristics of the SENDAS system will be described and the preliminary results of the INGV benchmark test will be shown.

Megalandslides and possible earthquake-induced landslides in the Atacama Desert (northern Chile, Southern Peru)

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Keywords: large landslides, Atacama desert, Chile, earthquakes.

The portion of the Atacama Desert between Northern Chile and Southern Peru is one of the most highly seismic areas worldwide. This area is also one of the driest desert in the world with precipitation of few millimeters per year. At the same time, the area is crossed by large and deep valleys excavated by the rivers flowing down from the Andes. Along these valleys, we surveyed and mapped enormous landslides affecting large portions of the valley flanks. To study these phenomena, to understand their origin and the triggering phenomena we carried out field surveys, we accomplished a regional landslide inventory from the coastline up to the Andes and we performed 2D and 3D limit-equilibrium slope stability analyses. In total, we recognized almost 500 large scale phenomena with volumes ranging between 10^{-3} km^2 to 464 km^2. For about 60 landslides we reconstructed the possible failure surfaces using topographic data and considering all the main features mapped and visible for each landslide. This allowed to compute the landslide volumes, and to perform back analyses of slope stability. This back analysis shows that a seismic input is needed to make slope instability possible, and that the presence of water in the slope during landslide instability is not necessary but highly probable.

For all the large landslides, characterized by a deposit crossing and damming the valley bottom we computed also the amount of material that has been eroded by the rivers and probably driven downstream up to the ocean.

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Landslides on Earth and Mars: similarities and differences

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Keywords: Mars, dynamics, rock avalanches.

Martian landslides are often far better preserved than their terrestrial counterparts, but their environment of deposition is still poorly known. Thus, a comparison between terrestrial and Martian landslides is a inspiring avenue not only to understand the role of different gravity acceleration on the landslide dynamics, but also to infer the environment of deposition of Martian landslides. We have compared Martian and terrestrial landslides, seeking for similarities and differences, and exploiting the information available for the terrestrial ones. To limit our field of interest, we have considered especially, but not exclusively, the Martian landslides from the Valles Marineris gorges. Our study is both statistical (i.e., all the landslides in Valles Marineris are mapped and measured and their morphological parameters are fitted with analytical expressions) and specific to a few cases, which are considered in more detail. The apparent friction coefficient for terrestrial landslides, object of numerous compilations, is compared to a similar data set for Mars; such data confirm previous observations that Martian landslides are less mobile than terrestrial counterparts for a given volume, but that Martial landslides may be much larger in size.

We find that large landslides on Mars exhibit a series of peculiar features compared to terrestrial ones, such as the steep collapse close to the scarp and the extreme thinning and long runout in the distal part. It is found that the terrestrial landslides which resemble most those in Valles Marineris are the ones fallen onto glaciers, while correspondence with subaqueous landslides is, in most cases, poor. Due to the seismic nature of northwestern America, numerous large rock avalanches have collapsed onto Alaskan glaciers; these are the ones morphologically most similar to landslides in Valles Marineris.

A series of numerical simulations are also put forward to address basic questions concerning the possible position of ice during the flow. We also search systematically for those distinctive morphologies that could be traced back to the presence of extensive amounts of ice in Valles Marineris. The undistorted appearance of Martian landslides, in contrast to the Sherman landslide in Alaska, indicates that if a glacier was present in the valley, it was not flowing. The superposition of several stacked landslides in Valles Marineris still exhibiting linear furrows shows that either ice was continuously renewed, or another source of not meteoric ice was present (possibly in the soil) to lubricate the landslides.

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Triggering and deformation mechanism of the Vaiont landslide through analogue and numerical models

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Keywords: Analogue modelling, Numerical modelling, Deformation analysis, Landslide dynamics, Vaiont.

The Vaiont landslide (Southern Alps, Italy) represents one of the most catastrophic landslides in the world recorded in the modern history. Due to its unexpected behaviour, the Vajont rockslide has been the subject of a number of studies since the days immediately following the October 9, 1963 catastrophe, until today and the researchers do not completely agree on some main questions, particularly regarding the triggering mechanism, the type of materials along the sliding surface and the evolution of its internal deformation.

In order to obtain a better understanding of the Vaiont disaster, a multiple analysis of the triggering mechanism and sliding behaviour have been performed using analogue e numerical models.

A finite difference numerical model has been built, in order to investigate the role of the internal strength of the rock mass in the triggering mechanism of the rockslide. The analyses were performed through the FLAC software, ver. 4.0 (Itasca 2000); a limit equilibrium analysis based on the Morgenstern and Price method has been performed by employing the Slope-W software, ver. 4.0 (Geoslope 1998) while the wedge method, proposed by Sarma (1979), were performed through a specific MS Excel spreadsheet with the aim of considering the effect of high pore pressures along the shear zone. To further support the results from traditional and numerical modelling, an analogue model was built, in order to get insights into the internal and surficial deformation patterns of the Vajont rockslide (Del Ventisette et al., 2015).

The friction angle values along the shear zone back-calculated through the numerical modelling range from 15° to 16°. This values are quite lower than those calculated by means of the traditional limit equilibrium method, thus suggesting the presence of pre-sheared material with residual strength along the basal shear zone.

The internal deformation of the analogue model, agrees with the numerical modelling results and geological cross sections, suggesting that the rockslide initiation was probably accomplished by the development of some new fractures within the rock mass.

The numerical and analogue modelling, as well as the stability analysis results suggest that the main collapse can be associated to the abrupt displacement increase due to the onset of brittle ruptures within the rockslide mass.

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3D High-resolution seismic tomography on a Tuff Cliff in the Sorrento Peninsula, Italy

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Keywords: Landslide hazard assessment, 3D High-resolution seismic tomography, Tuff cliff, Sorrento Peninsula.

This paper shows an example of 3D high-resolution seismic tomography that implements an acquisition geometry, which provides for the housing of sensors in the sub-vertical discontinuities of a tuff cliff.

The site test was located in the Sorrento Peninsula, a major Quaternary morphostructural unit of the western flank of Southern Apennines, consisting of a narrow and elevated mountain, that separates two major embayment of the eastern Tyrrhenian margin. The overall geological setting is characterized by a carbonate bedrock, covered by pyroclastic deposits (i.e. “Campania Ignimbrite”), originated from the Campi Flegrei volcanic district. The occurrence of steep slopes and the high relief area, along with the marine erosion at the base of the coastal cliff, creates favorable conditions for the occurrence of a generalized instability of the slopes characterized by tuff rock falls as prevailing landslide phenomena. An accurate prediction of these mass movements is difficult if not accompanied by an intensive hydrogeological and geotechnical monitoring and hazard assessment; the instability phenomena, in fact, can be caused by the presence of pervasive fracturing and cavities in the tuff rock. Due to logistical reasons, it is not possible to perform seismic surveys using typical acquisition setup, therefore we utilized a particular experimental procedure, characterized by an acquisition geometry which included the installation of the sensors on the tuff cliff and energize along concentric semicircles to obtain the maximum of the seismic resolution.

A non linear seismic inversion was used to obtain 3D High-resolution seismic tomography in terms of P-wave velocity and S-wave velocity. The interpretation of the experimental results in terms of 3D Vp/Vs ratio showed anomaly zones in the investigated rock. We identified an area with a low Vp/Vs value that we ascribed to a medium porosity or in dry condition with respect to the surrounding rock mass.

Effects of bedrock structure on engineering geological mapping of Slope Deposits: examples from Southern Alpi Apuane (Italy)

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Keywords: Engineering geological mapping, slope deposits, cluster analysis, bedrock geological structure.

Engineering geological properties of soils that cover the geological bedrock (Slope Deposits, SD) are relevant information for issues like soil erosion evaluation, landslide hazard assessment and hillslope hydrology. However, the high cost of SD characterization makes it necessary to apply reliable approaches aimed at extrapolating local observation data to neighbouring regions. Although different approaches for point data regionalization are available in the literature, recently some Authors have obtained engineering geological maps of SD by means of cluster analysis. By this approach, in those areas where physiographic factors may be considered constant, topography is assumed to be as the main factor determining the SD engineering geological properties. The method allowed obtaining reasonable SD maps, but the accuracies may be at times not satisfying. Therefore, with the aim to improve the prediction rate of SD maps, the effect of bedrock structure on SD engineering geologic properties is here analyzed and modelled.

Three study areas have been chosen in the Southern Alpi Apuane, where the geology is well known and both outcrops extent and distribution allowed to perform a detailed analysis:

- the Riomagno-Ripa sector (metamorphic Massa Unit), formed by Triassic quartz-muscovite, light gray to gray-greenish, seldom violet-gray phyllites with interlayers of dark metapelites and fine to coarser metaconglomerates with whitish to light pink (less abundant) quartz clasts (Verrucano Group);
- the Retignano-Ruosina sector, where the early Paleozoic light to dark gray and gray-greenish, more or less quartzitic, muscovite-chorite phyllites widely crop out (Lower Phyllites of the pre-Alpine basement of the metamorphic Apuane Unit);
- the Volegno-Cardoso sector, made up of quartz-feldspathic metasandstones with intercalations of 1-50 cm thick, dark gray to blackish phyllites and metasiltites (Pseudomacigno formation, top of the Apuane Unit Alpine series).

The engineering geological characteristics of SD have been obtained by integrating extensive field survey and lab data. Combining the main foliation map with hillslope topography, areas with homogeneous intersection relationships (foliation-topography domains) have been identified.

The morphometry of domains has been statistically described and compared. Then three different SD mapping processes have been performed by: a) using the morphometric parameters only; b) stratifying the analysis by the foliation-topography domains; c) integrating the domains into the clustering process after performing a rank analysis.

The output maps have been combined and compared and an assessment of accuracies has been performed. Finally the ratio between costs and benefits have been also evaluated in order to judge the suitability of the procedure for regional mapping of SD engineering geological properties.

Geomorphic analysis by 2D discrete wavelet transform applied to multi-temporal LiDARs of an area affected by a large deep seated landslide

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Keywords: Multi-temporal LiDAR, 2D discrete wavelet analysis, deep seated large landslide, risk mitigation.

The geomorphic analysis of areas affected by very slow deep seated landslides and their evolution is a hot topic, since these landslides have time-spread impacts, which may impact on human structures and infrastructures with severe consequences. Therefore an accurate evaluation of the geomorphic forms and the assessment of their evolution is very important, in order to prevent them from impacting on infrastructures. During the last decades, the availability of hi-resolution digital elevation models (DEM), obtained as airborne LiDAR is increasing as well as their cost is decreasing. The relatively low cost of these surveys permits to repeat data acquisitions manifold times. These allow somehow to scan the evolution of the landslide on multiple years. Ideally, the comparison of LiDARs corresponding to different times, i.e. years or months, should provide clear and direct information on the evolution of the landslide. However, this is not necessarily true, since DEMs based on LiDARs contains a lot of information, which must be separate and classified, in order to get the evidences on the landslide at stake. This work presents a case study of a slow large deep seated landslides involving a varicolored clay slope in Italy, in the south Apennine, close to the town of Potenza (Vassallo et al., 2016), where four LiDARs, collected on a range of 7 years are available. The comparison of these LiDARs allows for getting some interesting morphological information on the main geomorphic characteristics of the area and their evolutions: new phenomena, variation of the bounds, impacts on infrastructures. In addition, here a numerical classification of the evolutions of the landslide is proposed. This analysis is based on 2D discrete wavelet transform (2D DWT) (Doglioni and Simeone, 2014; Doglioni et al., 2015; Galeandro et al., 2013). The obtained maps can be used as a support for planning the management of the infrastructures and use of the involved area and for mitigating the risk. In particular, risk and susceptibility maps can be periodically updated, by using the numerical information extracted by 2D DWT.

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Examples of vertical geostructural maps of tuff cliffs (Campi Flegrei, Italy) derived from Terrestrial Laser Scanning and Digital Photogrammetry techniques.

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Keywords: Terrestrial Laser Scanning, Digital Photogrammetry, tuff cliff, geostructural map.

Terrestrial Laser Scanning and Digital Photogrammetry are geomatic techniques which have been increasingly applied for rock slope characterization. Generally, such techniques allow geologists to produce 3D point clouds from which accurate Digital Elevation Models (DEMs) can be achieved by means of the point interpolation. In rock slope environments, structural discontinuities, unstable blocks and other geological/geomorphological features can be analyzed with these techniques.

In this contribution, we present a long-range terrestrial laser scanner and digital photogrammetry application for the geostructural mapping of two tuff cliffs located along the coastal zone of the Campi Flegrei volcanic district, near Naples (Matano et al., 2015a, b). Data acquired with geomatic techniques were elaborated with specific software and then combined with data obtained from structural field surveys carried out by climber geologists and geomorphological analysis. In order to develop a 2-D digital map for the cartographic representation of geostructural information, we managed all spatial data in GIS (Geographical Information System) environment.

The main products of this study are vertical geostructural maps of the Coroglio and Punta Epitaffio cliffs at 1:500 scale, illustrating the spatial distribution and orientation of the major families of structural discontinuities detected along the exposed surface of the cliffs. The cartographic products include base information useful to identify the main rock failure mechanisms along the cliffs and represent a first step for the zonation of areas susceptible to block failures and planning of monitoring activities.

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Relationship between slope instability and active tectonic: Gimigliano case study in Calabria Region (Italy)

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Keywords: Landslide, Active Tectonic, Geomorphic Index, Gimigliano, Central Calabria.

In this paper preliminary results of the PhD project «Ground Displacements due to Tectonics and Gravity: SAR observations of surface deformations» are presented. This work provides a detail detection of landslide-induced displacements at local scale in Gimigliano site, Calabria Region. Several landslide occurrences and the relationships of some controlling parameters with various events have been evaluated using GIS techniques and correlated with measured geomorphic indexes. Gimigliano area lies on Liguride and Calabride Complexes, including a significant *tectonic window* on Mesozoic ophiolite rocks. The metamorphic nappes show tectonic boundaries marked by pre-Neogene sub-horizontal thrusts, striking NE-SW, displayed by Neogene-Quaternary regional NW-SE transpressive fault zones. The well-structured fault system generates many wide cataclastic zones represented by intensively weathered crushed rocks (Tansi et al., 2007). Landslide phenomena are widespread across time up to nowadays all over the Gimigliano area. Mass movements are mainly triggered by intense precipitation that usually occurs in single daily rainfall events, causing a strong impact rock weathering and degradation. Beside with shallow landslides also deep-seated gravitational slope deformations have been recognized in the whole area (Bianchini et al., 2007).Landslide inventory maps document the extent of landslide phenomena in a region and show information that can be exploited to investigate the distribution, types, pattern, recurrence and statistics of slope failures.This paper presents results obtained to assess the influence of active tectonics as one of the different determinant factor to be accounted for GIS landslide susceptibility mapping. This was made by an approach based on using different active tectonics geomorphic indexes (El Hamndouni et al. 2006). Regarding the active tectonic factor, the GIS analysis provides a significant correlation with different types of landslides occurrences. These correlations between density of landslides and active tectonics intensity, expressed by geomorphic indexes, suggest the usefulness of the integration of the active tectonics among the main determinant factors in landslide susceptibility assessment of the Gimigliano area which may be applied to similar areas around the world.

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Application of a new methodology for landslide susceptibility assessment in the urban area of Napoli, Italy

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Keywords: Landslide susceptibility, Statistical approach, Monte Carlo Markov Chains, MaxLike, Napoli.

Since at least 1997, engineering geologists focused on the city of Napoli, Italy: in this context, landslides' peculiarity is not their magnitude, rather modest, but their close interaction with the anthropic fabric (Di Martire et al., 2012). Based on previous knowledge and thanks to ever more detailed starting data, in recent years studies dealt with landslides susceptibility modelling, in particular on the improvement of statistical methodologies. On this occasion, a methodology is applied which is widely employed in ecology to draw prediction maps for species' occurrence probability. This set of procedures defined as "Species Distribution Modeling" (SDM) includes different statistical approaches (mainly Bayesian) to predict the occurrences of an event in unsampled locations. Due to the lack of common guidelines by the scientific community, seven predisposing factors to instability were selected based on more than twenty years of experience on shallow landslides occurred at Napoli and in the surrounding areas. They are: slope, aspect, lithology, land use, distance to streams, to roads and to rocky scarps. Slope, aspect and distance to rocky scarps were extracted from a high resolution Digital Elevation Model (LiDAR data 1 m × 1 m grid cell); lithology and land use layers were obtained from corresponding maps produced by the municipality of Napoli; distance to streams and to roads were obtained from Regional Topographic Map. Morphological and geological layers were considered as predictors in a recently developed SDM method named MaxLike (Royle et al., 2012). This method allows the estimation of an event occurrence probability by using the Bayes' rule to compute the conditional probability of environmental variables given the known events' occurrences and then uses maximum likelihood to estimate parameters. Prior to this, Monte Carlo Markov Chains via Gibbs sampling was used to model and then remove spatial autocorrelation from the predictors. The study area is represented by the densely-populated districts of Soccavo, Pianura and Arenella, dominated by Camaldoli Hill, which is the most prominent peak of the entire Phlegrean district (458 m a.s.l.), and is the site where more than 300 landslides, of the over 1300 events recorded at Napoli, occurred. The results were critically evaluated using validation datasets (Receiver Operating Characteristic - ROC curves), by means of Sensitivity-Specificity graphs where Area Under Curve (AUC) was estimated. Susceptibility map was then compared to the official map provided in the Hydro-geomorphological Setting Plan (HSP) redacted by the competent governmental agency (River Basin Authority) by means of a semi-statistical approach already in use by the research group (Calcaterra et al., 2003).

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Hydrological monitoring of landslide-prone soils covering Camaldoli Hill slopes (Napoli, Italy)

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Keywords: soil slip initiation, field monitoring, hillslope hydrology, pressure head.

Many rainfall-induced shallow slides or soil slips (Campbell, 1975), not evolved to flows (Hungr et al, 2001), occurred on Camaldoli hill slopes, Napoli, on March 4-6, 2005. This event involved soils derived from the weathering processes of the volcanoclastic sequence present in the area. Although they caused no fatalities, however they confirmed an important hazard impending over the foothill population (Di Martire et al., 2012).

The Camaldoli hill is located in the northeastern part of Phlegreean Fields (Campania, southern Italy), which is an important volcanic district related to the Plio-Quaternary graben structure of the Campanian Plain and whose slopes characterize many areas of Napoli and of its province. Falls, topples, slides and flows occur in this area involving lithoid (tuff, lavas) and incoherent materials (top-soil and/or pyroclastic horizons) and representing a recurrent threat following long-duration and/or intense precipitations.

This study shows the preliminary results of a soil pressure-head monitoring at different depths (started in 2015) along the SW slope of Camaldoli hill, focused on comprehending the hydrological behaviour of these soils. In-situ investigations (geognostic drillings, DPLs topographic measurement, permeability tests) and sampling for laboratory tests were carried out. Sensors with different measuring ranges were used: four *tensiometers*, four *Watermark sensors* (Spectrum Technologies) and five *MPS-2 sensors* (Decagon technologies).

Monitoring data showed a constant pressure head regime ranging from -1.0 m to -4.0 m during the winter rainy season due to the combined effects of rainfall, evapotranspiration and unsaturated water flow circulating downslope and into the deepest horizons. Starting from spring until the late summer, an exponential increase of pressure head was recorded (down to -20.0 m) due to the joined effects of lower rainfall, increasing air temperature and evapotranspiration rate.

This experimental observation has a strong influence on the setting up and calibration of hydrological numerical models as well as on results of the related slope stability models which will be used to simulate unsaturated/saturated hydrological critical conditions leading to initial instability by means of a deterministic approach.

Finally, the expected results will allow setting up a consistent early-warning system based on the monitoring of rainfall data and soil hydrological parameters.

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Kinematics and sediment discharge of earth flow: an example from southern Italy

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Keywords: Earth flow, sediment discharge, GPS surveys.

Earth flows worldwide distribution, their complex behavior, and their impact on human activities make them an important subject of study. In the last five decades, several studies have contributed to the knowledge of these natural phenomena and the number of publications has grown with the number of registered damaging earth-flow events (e.g. Guzzetti and Tonelli, 2004). These studies have contributed to the understanding of earth flow kinematics and dynamics (e.g. Coe et al., 2003; Handwerger et al., 2013). However, only few studies deal with the combination of measured displacement and velocity data, and calculated strain for the characterization of earth flow behavior (e.g. Prokešová et al., 2014).

We use data from GPS surveys, boreholes, seismic profiles, ambient seismic noise acquisition, T-LiDAR surveys, and the mapped distribution of deformational structures on the earth-flow surface (Guerriero et al., 2016), to characterize the short-term behavior of the Mount Pizzuto earth flow in southern Italy. This earth flow affects the northeastern side of the Pizzuto Mount, and involves an estimated volume of 300,000 m^3 of fine-grained flyschoid material (Guerriero et al., 2016). It has a complex source area with two branches, a 500 m long transport zone, and a fan-shaped bulging toe. It is one of the most active earth flows of the Benevento Province (Revellino et al., 2010), causing direct damages to properties and indirect effects on the local road and service lines, which have been destroyed several times by the earth-flow induced floods. The movement of this earth flow is highly seasonal with major acceleration/reactivation concentrated in the spring (e.g. Guerriero et al., 2015).

In this work, we use displacement data from 17 GPS surveys on the earth-flow surface, and the reconstructed 3D geometry of the earth flow to compute sediment discharge at kinematic-zones transition sections, relating it to the effects of internal strain. This allows us to understand mechanisms of sediment transport along the flow, changes of flow velocity during both ordinary and extraordinary (i.e. surge) movement, and the control exerted by the basal-slip surface on the earth-flow velocity. The GPS surveys were completed between April 2014 and March 2016, while data constraining the depth of the basal-slip surface were acquired between December 2014 and February 2016. Since the Mount Pizzuto earth flow discharges sediment into the channel network and has influenced the capacity of the Ginestra torrent, a complementary aspect of this work is to evaluate the amount of sediment entraining the hydrographic network and the potential influence of the earth-flow on flooding.

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Why do we need conceptual models for landslides?

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Keywords: active landslides behavior, landslide evolution, conceptual models.

Dealing with landslides in real-practice often requires to supplement information of incomplete data sets. Best-case scenario consists on the knowledge of surface morphology and movements (deformation), geophysical parameters or remote sensing 2D or 3D imaging, geotechnical parameters characterizing the material, in addition to some boreholes. Nevertheless, most of this type of data are often partially known or even do not exist. In most cases the level of knowledge is low, but the mechanism understanding can be improved by using numerical modelling and expert interpretation. The main issue with numerical models is that the requested parameters such as friction angle, viscosity, young modulus, etc. are necessary to solve the problem, which again increases the number of unknown parameters, and in addition, they can change within the landslide body. Furthermore, there is also a difficulty linked to numerical models, because several material behaviors can coexist and/or evolve with time. As a consequence, conceptual models are a way to provide a general scheme of the spatial-temporal behavior of landslides and to set suitable monitoring system, at the right place and at the right time. In addition, conceptual models are part of a dynamical process of understanding and must be updated after each acquisition of new data. Several questions must be addressed to establish a conceptual model which are not always addressed in the same order as listed below:

• Integrate the surface data displacement with the depth information (boreholes, geophysics…)
• Define the surface and volume that is involved and identify and locate the types of movement; • Identify the main rheological mechanisms (friction, flow, …) and their relations in time and space
• Analyse the reaction of the landslide to external solicitations • Run numerical modelling to check the validity of the hypothesis.
• … Answering to these questions must lead to a conceptual model that could permit to forecast the landslide evolution.

This is the main point of a conceptual model: if it does not provide a satisfactory answer, it must be updated and refined, which is part of the process. This approach will be illustrated by several examples where the so built conceptual models provided the framework to help understanding the behavior of active landslides and/or for adapting the monitoring systems. For instance, it was possible to deduce from the geodetic data at the Randa rockslide (Switzerland) a reliable model that has been subsequently confirmed by other studies. Also, a reliable conceptual model was built for the Åknes rockslide (Norway), which allowed interpreting geo-electric data and geomorphology in the neighbourhood. In the case of earthflows we were able to forecast the future behavior, i.e. failure, of Pont Bourquin landslide (Switzerland), based on different data sets. In addition, geophysical data based on passive seismic monitoring provided new insight to describe the complex behavior of earthflows. Also to illustrate conceptual models, we can show with an a priori that the reaction of landslide to rainfall or piezometric level can be modelled by transfer function that integrates both a reaction and a relaxation. All these examples show how conceptual models help to better understand landslide mechanisms but also are a fruitful tool to raise the pertinent scientific questions.

Integration of advanced methodologies for rock slope failure monitoring: preliminary results of the Coroglio tuff cliff MOnitoring SYStem (MOSYS)

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Keywords: tuff cliff, monitoring, rock slope failure.

Monitoring of cliff stability is an essential task for the management of high-risk coastal urban areas. The use of monitoring systems is a standard practice to assess and prevent geological and geotechnical hazards, as rock failures along slopes, and plan effective actions for risk mitigation. Cliff failures have multiple predisposing and triggering factors, often depending on lithology, weathering and fracturing of rocks, exposure, as well as local meteorological and environmental conditions.

The implementation of an integrated system aimed at the real-time monitoring of a number of physical parameters controlling the rock slope stability is described in Matano et al. (2016). The complexity of the study resides in three main aspects: the lithology of the "soft rock" exposed on the cliff (Neapolitan Yellow Tuff), the proximity of the coastline, and the volcanic unrest of the area.

Remote sensing equipment like UAV digital photogrammetry and terrestrial laser scanning have been used for obtaining detailed multitemporal digital terrain models (DTM) of the cliff, as well as geostructural analysis and classification of the slope, supported by structural fieldwork.

The system has been installed on the Coroglio tuff cliff, located in the highly urbanized coastal area of Naples (Italy) at the border of the active volcanic caldera of Campi Flegrei. The monitoring system consists of standard geotechnical instruments (crackmeters and clinometers) coupled with a network constituted by Brillouin Optical Time-Domain Analysis (BOTDA) sensors (Bernini et al., 2007), a velocimetry sensor and a total weather station. Traditional geotechnical sensors and the optical fiber sensor have been installed across the fractures bordering selected unstable tuff blocks in order to provide a multi-parametric and integrated monitoring.

The preliminary results obtained during the monitoring activity (December 2014 – May 2016) are described and discussed. Micro-deformations of rocks measured by geotechnical sensors reveal a general sinusoidal pattern, likely associated with a periodic bulk volume variation of the rocks, as a response to seasonal and daily temperature variations. Next steps of the research will include an integrated analysis of all datasets and the definition of operational procedures for the real time monitoring definition of an automated forecasting procedure addressed to an early warning system.

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Rock slope stability modeling for risk assessment in a historical site of Sicily, Italy

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Keywords: Rock Slope Modeling, Stability Analysis, Rockfall, Risk, Simulation.

Rockfalls are considered one of the major natural threats in populated mountainous areas. Growing settlements often lead to a considerable spatial extension of endangered areas, as well as to a rising need for safety and protection of the population. This is especially true in areas experiencing increasing tourism. The case study presented herein is indeed focused on a touristic and historical part of eastern Sicily, renowned for its singular landscape, enclosing the Etna volcano and the Ionian coast. Here, the charming city of Taormina and its surroundings are popular travel destinations for visitors. In particular, in this mountainous sector a two-lane road is the only communication route between Taormina and the nearby village of Castelmola, of pre-Hellenic origin. Several researchers have studied the geological complexity of this area, highlighting how past and recent tectonics makes the steep and poor quality slopes prone to instability phenomena. Over the last decades, a number of landslides occurred in the area, threatening public safety. Pappalardo et al. (2014) and Pappalardo & Mineo (2015) studied the documented events, attaining a preliminary assessment of the risk both along a sector of the road and at an inhabited sector of the failure-prone cliff. Mineo et al. (2015) and Pappalardo et al. (2016) surveyed the rock masses of the area through InfraRed Thermography, proposing a new methodology for the study of intensely jointed rock slopes. Such researches highlighted relevant criticalities and the need for further detailed studies. Moreover, during the last two years, rainfalls triggered two further events: detached blocks hit a house and reached various segments of the road, fortunately with no injuries. Such events were taken into account for the stability modeling of the rock slopes through back analyses, which were performed to calibrate reliable simulations of possible future rockfalls. Moreover, a numerical stability analysis through deterministic and probabilistic approaches was carried out. Results highlighted several critical situations, involving also possible deeper mass movements, and allowed the identification of elements potentially at risk.

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An interdisciplinary approach for the characterisation of the clays involved in the catastrophic 1963 Vajont landslide

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Keywords: Vajont (Vaiont) slide, High-plasticity clay, Montmorillonite, XRD analysis, Residual friction angle.

High-plasticity clay levels played a decisive role in the catastrophic 1963 Vajont slide, as also emphasised by Hendron & Patton (1985) in the detailed geological survey of the large upper detachment surface. However, many geological and geomechanical issues still remain open, because the geological context of these clay layers was not described in detail. This lack prevents full understanding of the clay influence on the catastrophic slope failure and on the subsequent high velocity sliding into the Vajont reservoir. A specifically-addressed geomechanical survey has been performed over the recent years (2006–2015) and many clay levels have been sampled (Paronuzzi & Bolla, 2012). On the basis of this new data, an updated engineering-geological map of the Vajont landslide has been implemented (Paronuzzi & Bolla, 2015). The clays involved in the 1963 rupture were analysed according to an interdisciplinary approach that considers lithostratigraphical, mineralogical and geotechnical aspects. This work presents the main results of this interdisciplinary characterisation. The clay samples (20) belong to three distinct units: 1) the main rupture surface involving the cherty limestone bedrock (Fonzaso Formation: Upper Jurassic); 2) the basal shear zone of the Vajont slide (angular gravel with contorted clay lenses and sheared off rock masses); and 3) the upper part of the Fonzaso Formation outcropping on the opposite valley flank. Field evidence confirms the occurrence of discontinuous clay lenses having a thickness ranging from 0.5 to 5 cm, in most cases. Clay materials exhibit variable colours: greenish grey, pale olive, pale yellow, light grey, and even white. XRD analysis revealed a rather constant mineralogical composition, including calcite, quartz and montmorillonite (19 samples), whereas plagioclase have occasionally been identified (2 samples). Montmorillonite shows both a well-crystallised structure (class A) and a poor-crystallised structure (class E), thus influencing the shear strength characteristics. Laboratory investigations on the clay samples testify to a great variability of their geotechnical properties. The clay fraction ranges from about 10% to 60%. Three main groups of clay materials can be identified on the basis of their plasticity properties: low-medium, medium and high plasticity clays. The liquid limit varies considerably, ranging from 30% up to 90%. Clay samples were also tested in the laboratory through ring shear test apparatus to investigate their shear strength. The results of the shear tests emphasize a notable variation in the characteristic residual friction angle (φ_{res}) that ranges from very low (6.7–9.7°) to considerably higher values (25.1–26.7°), thus denoting a remarkable (and previously not pointed out) geotechnical variability of the clay levels involved in the catastrophic 1963 slope failure.

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Quantitative landslide susceptibility assessment of the Vernazza catchment (Cinque Terre National Park, Italy)

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Keywords: Landslide susceptibility, in situ tests, GIS, Cinque Terre, DPL, Frequency ratio.

Quantitative landslide susceptibility is a fundamental tool for engineers, scientists and urban planners. The Vernazza Catchment (Cinque Terre National Park, NW Italy), severely affected by shallow landslides and debris flows during the October 25th, 2011 event (500 mm of rainfall in less than 4 hours registered by the nearby Brugnato rain gauge), represents an excellent case study as to test different approaches and methodologies to reach a quantitative assessment of landslide hazard and risk.

To this respect, the basic principle of this approach (statistical and probabilistic) is that under similar environmental conditions, the spatial distribution of past and recent slope failures is the key for predicting slope movements in the future (Carrara et alii, 1995).

An accurate landslide inventory map has been realized through both geomorphological survey and analysis of orthorectified FVG (Friuli-Venezia-Giulia Geological Survey, 2011) aerial photos and updated to the actual slope conditions; the digital data set also includes a 5×5 DEM released by Regione Liguria and several raster format data such as slope, aspect, lithology, stream distance (giving proportional weight at stream size based on a hierarchy of tributaries) and road distance, land use. Among the inventoried landslides, only planar and rotational slides were here considered.

A bivariate statistical approach was used in order to establish which parameter class has more influence in landslide triggering.

Secondly, geotechnical parameters such as peak friction angle and relative density obtained by original in situ tests (dynamic cone penetrometer) were interpolated and extended to homogeneous lithology categories. PFAS (Peak friction Angle minus Slope) values were then considered in the statistical method.

Soil under study results of two main types from degradation of the Macigno and Canetolo formation: soil depth ranges from 0,9 to 3,4 meters on terraced slopes and from 0,6 to 2,1 meters on slopes covered by woods. Average D*r* (relative density) and φ' (friction angle) values for both soil types derived from Macigno and Canetolo formations were obtained: D*r* values range from 40,3 to 53,1 and φ' ranges from 38,0 to 42,7 for the first ones, while D*r* ranges from 24,9 to 49,3 and φ' from 31,0 to 41,7 for the second ones.

Preliminary results evidenced that slopes characterized by high steepness and SW-oriented were extremely hit by planar, rotational and shallow landslides, along with a high susceptibility to slope instabilities of the Argille e Calcari di Canetolo formation.

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Re-analysis of multiple surveys GNSS data collected in a DSGSD context developing in Scopello (NW Sicily, Italy)

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Keywords: DSGSD, landslide, GNSS.

The knowledge of landslide kinematics is a basic requirement for studying landslide mechanisms and predicting their hazard. The most efficient way to study kinematics of landslides is the direct measuring of the surficial displacements. In the past two decades, GNSS techniques have been widely applied to landslide studies, both as a complement and an alternative to conventional surveying methods. The state of art demonstrates that high-accuracy GNSS techniques are an efficient tool in landslide study. Compared with conventional surveying techniques, GNSS generally increases the survey accuracy, productivity, and monitoring capability, in addition to reducing cost. Actually to obtain a comprehensive information about the landslide characteristics, the GNSS derived information should be integrated and correlated with the geomorphological, hydro-geological and morpho-tectonic characteristics of the area.

Deep-seated Gravitational Slope Deformation (DSGSD) phenomena in the Scopello area (NW Sicily, Italy) have been studied since the late eighties. Lately, in 2000, a GNSS network was realized for monitoring the landslide phenomena in that area. The GNSS network consists of 27 vertices, 7 of which are located outside the landslide area; the latter are intended to be used to realize a very local reference system, in respect to which the displacements of the vertices in the landslide area can be calculated.

GPS data collected during three campaigns spanning 2000-2005 time interval are analyzed by means of Gamit-Globk 10.6 software suite. Data are processed following a conventional approach, based on the carrier-phase double-differences network resolution for static (longer than 4 hours) landslide monitoring.

The analysis has led to model the displacement field and improving the geomorphological models of Scopello DSGSD and its evolution over time with a special focus on reactivation processes.

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Geomechanical and morphometric analysis for assessing rockfall susceptibility using high resolution 3D model. The case study of "Palinuro Natural Arch" (Cilento coast, Southern Italy)

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Keywords: Terrestrial Laser Scanner, UAV, Rockfall Susceptibility, Cliff.

Rockfalls are widespread phenomena threatening human beings and causing significant damages to structures (Agliardi et al., 2009). Moreover, the high speed and kinetic energy of rockfalls make failure forecasting and mitigation action very complicated.

In the coastal zone rockfalls and other types of landslides are the dominant and more visible phenomena in the process of sea cliff retreat (Sunamura, 1992). This situation determines a significant source of natural hazard and a constraint for human activities. In fact, the increasing human use of cliffy coastal areas made cliff instability phenomena a problem with growing importance in several areas of the world (Redweik et al., 2009). The rocky coast often lead to problematic condition for accessibility and safety of the field, then the remote sensing techniques are very helpful.

In this work we present an approach to assess rockfall susceptibility using geomechanical field surveys integrated with different remote survey methodologies, such as Terrestrial Laser Scanning and UAV (Unmanned Aerial Vehicle) photogrammetry.

The test area is a coastal cliff situated in the southern part of the Cilento (Centola Municipality, Campania Region). This cliff is constituted by heavy fractured carbonate rock masses with strong structural control and is characterized by a natural arch developed since last interglacial. The "natural arch" beach is an important geological feature of high tourist attraction, but currently the bathers fruition is forbidden for high rockfall risk.

During last year several surveys were performed using different remote sensing techniques. The database carried out is constituted of Terrestrial Laser Scanner and photogrammetric point clouds and of hundreds ground-based and UAV high resolution digital photographs, which has been used to produce also a high resolution 3D model. The results of geomechanical characterization (ISRM, 1978) and of geostatistical analysis in GIS environment (Geographic Information System) have been compared in order to define the main failure mechanisms and the critical structural features. The geomechanical properties of rock masses have been studied further by using a morphometric analysis of the 3D model. As a result, a rockfall susceptibility assessment was achieved and the different classes of susceptibility to failure at cliff scale are shown by a frontal perspective map.

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Regional sensitivity analysis applied to shallow landslide susceptibility assessment

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Keywords: Regional Sensitivity Analysis, Shallow landslide, Kolmogorov Smirnov test.

Urbanization growth and effects of climate change make shallow landslides an increasing source of risk in mountain regions. Therefore, in the last three decades, the interest by scientific community toward this topic grown. One of the main aims of research projects involving shallow landslides, is to perform robust hazard assessment for wide areas (regional assessment), in order to support sustainable spatial planning. Currently, three main methodologies may be implemented to assess regional shallow landslides hazard: expert evaluation, probabilistic (or data mining) and physically based models methods. Concerning the latter, both the limited availability of geotechnical data for the involved soils (Slope Deposits, SD) and the model assumptions limit the reliability of susceptibility assessment. Therefore, in this work both the relevance of chosen model and input parameters in determining the output variability has been evaluated.

Although in the literature many methods have been used to perform sensitivity analysis, in this work the Regional Sensitivity Analysis (RSA) (Spear & Hornberger, 1980; Young et al., 1978) has been adopted. Therefore, this study has the dual purpose to assess the importance of each input parameter for shallow landslide susceptibility assessment as well as to perform a thorough analysis of pros and cons of the RSA method.

The study area (about 350 km2 wide) is located in the north of Tuscany. The bedrock is mainly made up by the Macigno formation sandstone. The engineering geological properties of SD, such as: depth, unit weight, friction angle, cohesion and hydraulic conductivity, have been obtained by a considerable field survey, laboratory analyses and in-situ tests. For each parameter, the most appropriate probability density function has been evaluated and implemented in the further analysis. Some of the most popular models available in the literature for shallow landslide susceptibility/hazard evaluation, have been chosen to be analysed (e.g. SHALSTAB, SINMAP and TRIGRs). The RSA has been performed by using different evaluation thresholds. Moreover, different input parameter scenarios have been implemented taking into account the field survey outcomes. The results have been compared in order to investigate: which input parameter is the most influential to the model output response; models behaviours; effects of adopted input data scenarios; feasibility of applying the RSA to physically based models for shallow landslide susceptibility evaluation.

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SESSION S28

Geomorphological mapping as a fundamental tool for hazards assessment and risks mitigation

CONVENERS AND CHAIRPERSONS

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The "Franarisk" project in Rome metropolitan territory: preliminary results and remarks

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Keywords: susceptibility analysis, risk assessment, landslide inventory.

In the frame of its institutional due, the former Provincia di Roma (now Città Metropolitana di Roma Capitale) promoted since 2005 a series of study activities in order to analyze the landslide susceptibility of its territory, as a preliminary step in a broader process aimed at landslide risk assessment. Methodology was firstly outlined by partnering with Roma TRE University and ENEA. The susceptibility analysis is based on the quantification of relations between landslides, inventoried in the institutional database and integrated with ad hoc surveys, and a number of predisposing parameters, represented in 1:10,000 scale. By partnering with Sapienza- University of Rome- Department of Earth Sciences, a study has been recently carried out aimed at the homogenization of data and studies to date produced. The study can be summarized as follows:

1. in a first instance we completed the analysis of the susceptibility of the eastern and southern portion of the Province through the application of the heuristic method "ENEA-Roma TRE", which implies the attribution weights and indices to the predisposing factors according to largely subjective criteria.
2. after a first attempt of "mosaicking" the results obtained in the 2005-15 period with the heuristic method, we faced a substantial inability to make comparisons between different map products, in which the susceptibility levels (expressed in qualitative scale from very low to high) are strongly linked to weight/index heuristically assigned. To overcome this problem, the entire dataset available has been homogenized within an overall geodatabase; the analyses were then repeated according to the Frequency ratio method, which guarantees an objective criterion for the assignment of weights to predisposing parameters. This analysis, suitably validated with test datasets, allowed us to produce a homogeneous cartography of susceptibility to different types of landslides.
3. Finally, the overall dataset, suitably divided into training and testing subdatasets, was analyzed with the technique of logistic regression, which provides more objective and easily interpretable results in terms of susceptibility levels, these being expressed as probability of each mapping unit to belong to the "landslide" class. Results were satisfactory but not optimal because the statistical method strongly depends on numerosity of the "population" landslides.

In conclusion it can be stated that: i) the adoption of a uniform and updated database of environmental data (i.e. predisposing factors) in a detailed scale has been started, regardless of the specific purpose of the analysis; ii) the analyses performed to date have provided an extensively validated product that is a useful tool for spatial planning and represents an operating standard for subsequent analyses on the territory still to be analyzed; iii) the comparison between the three relevant analytical methodologies allows a critical comparison of pros and cons of each of them.

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Mapping wide gravitational processes: the cases of DSGSD and huge landslides in Central Apennines and related hazard scenarios

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Keywords: Geomorphological mapping, Gravitational phenomena, Hazard assessment, Central Apennines.

This study, focused in the central Italian Apennines, shows some geomorphological mapping resources in achieving a functional cartography to assess the hazard related to wide gravitational phenomena.

The research area includes the section of Marche Ridge between the Chienti (northward) and Fiastrone (southward) rivers, where the prevalently carbonate lithologies of the Umbria-Marche Succession, already known in the literature, outcrop. In particular, the above lithologies ranging from more calcareous terms, resistant and brittle, up to weak and ductile terms, less consistent in thickness, but no less significant in the relief evolution. The structure is that typical of this Apennine chain sector: according to a folds and thrust system, East vergent and developed in Miocene-Lower Pliocene times. The compressive cinematics was followed by an extensional tectonic phase that created new discontinuities and sometimes resumed the former ones.

More in detail, in the observed area were surveyed and mapped many gravitational phenomena; among the larger ones and those with DSGSD characters, this paper draws an evolutionary scheme for the cases of Borgiano and Mt. Fiungo (Chienti valley) and of Mt. Fiegni and Mt. Frascare (Fiastrone valley). Along the slopes have occurred and are also still active the conditions predisposing and triggering huge and impressive gravitational phenomena: high relief, ductile lithologies intercalated with brittle ones, discontinuities and bedding out of the slope (Dramis et al., 1988; Aringoli et al., 1996 and 2010). The high seismicity of the region also integrates the framework of predisposing and triggering factors. In these areas, deep gravitational movements not only affect the slopes along the major valleys incisions, but also disturb the entire anticline structure, with deformation set at different depths, driven by both lithological (weakest levels) and structural (thrust, tectonized bands) discontinuities. These phenomena are manifest with the characteristic morphological elements, whose mapping are often hardly adaptable to classical schemes; therefore it was necessary to create some special symbols and new graphical tips.

The objective is to make easy to read the evolution of these huge gravitational process, especially if hazard components are there associated, thus extremely useful in the land use planning.

Aringoli D., Gentili B. & Pambianchi G. 1996. The role of recent tectonics in controlling the deep-seated gravitational deformation of Mount Frascare (Centra Apennine). Geogr. Fis. Dinam. Quat., 19, 281-286.

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Proposal of a new geomorphological legend for flood hazard evaluation and associated risk. Study cases in the Marche region (central Italy)

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Keywords: Geomorphological mapping, Flood hazard, central Italy, Marche region.

In the recent years, the Italian Association of Physical Geography and Geomorphology (AIGeo), is studying a new geomorphological legend, highly applicative, aimed at the recognition and representation of geomorphological hazards in a context of territorial planning and for the definition of possible future risk scenarios.

The opportunity to experience this new legend is coming from the collaboration between the University of Camerino and the Consorzio di Bonifica of the Marche region, started in 2015, with the purpose of outlining the criticalities of the central Marche fluvial networks in the sector between the River Tenna to the south, and the river Misa to the north, and to provide proper documentation about risk scenarios and remediation. In this sector a lot of anthropic structures present along the river beds are critical elements because they significantly reduced the flow regime; moreover the change in the trend of precipitation of the recent decades (with violent and devastating rains concentrated in a very short time) created high hazard conditions. To evidence this aspects an in-depth geomorphological survey has been carried out with the aim of acquire relevant information about the active and intense geomorphological processes and the elements required for the proper evaluation of the impact of the anthropic infrastructure along the river bed.

A former step allowed the drafting of more than 1,000 "census sheets" containing all the information needed; after that a new experimental geomorphological mapping (containing new symbols and information to characterize the flood hazard and its impact on the anthropic works) has been edited for some test areas.

The study, still in progress, has confirmed the need for a new type of geomorphological legend as a tool for the recognition, characterization and representation of natural hazards (specifically those related to flood phenomena) and of their relationships with human works.

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DSGSDs and huge landslides in the Central Apennines (Fiastrone and Chienti Valleys): comparison between structural-geological and geomorphological features

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Keywords: DSGSDs, Landslides, Structures, Relief evolution, Central Apennines.

This research, focused in the central Italian Apennines, shows the possible relationships between structural-geological and geomorphological features, related to gravitational deformation of wide slopes and ridge sectors.

The study area includes the section of Marche Ridge between the Chienti (northward) and Fiastrone (southward) rivers, where the prevalently carbonate lithologies of the Umbria-Marche Succession, already known in the literature, outcrop. In particular, the above lithologies ranging from more calcareous terms, resistant and brittle, up to weak and ductile terms, less consistent in thickness, but no less significant in the relief evolution. The structure is that typical of this Apennine chain sector: according to a folds and thrust system, East vergent and developed in Miocene-Lower Pliocene times. The compressive cinematics was followed by an extensional tectonic phase that created new discontinuities and sometimes resumed the former ones.

In the examined zone the Marche ridge is characterized by the Mt. Fiegni anticline, on the roof of the "Sibillini Mountains Thrust" (Pierantoni et al., 2013); this anticline is aligned in NNW-SSE direction and is orthogonally interrupted by the hydrographic network such in the examined sector, where the rivers Chienti and Fiastrone strongly downcutted the ridge and created valleys with high relief, sometimes exhuming even the lithostratigraphic sequence weak levels. Along these slopes have occurred and are also still active the conditions predisposing and triggering huge and impressive gravitational phenomena: high relief, ductile lithologies intercalated with brittle ones, discontinuities and bedding out of the slope (Dramis et al., 1988; Aringoli et al., 1996 and 2010). The high seismicity of the region also integrates the framework of predisposing and triggering factors.

More in detail, in the observed area were recognized and surveyed many gravitational phenomena; among the larger ones and those with DSGSD characters, this paper draws an evolutionary scheme for the cases of Borgiano and Mt. Fiungo (Chienti valley) and of Mt. Fiegni and Mt. Frascare (Fiastrone valley). In these areas, deep gravitational movements not only affect the slopes along the major valleys incisions, but also disturb the entire anticline structure, with deformation set at different depths, driven by both lithological (weakest levels) and structural (thrust, tectonized bands) discontinuities. These phenomena are manifest with the characteristic morphological elements, showing the close relation with the geological ones, while generating new structural features not fully sortable in the classical tectonic evolution of the Apennines.

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Proposal of geomorphological cartography of hazard from debris flows: example from Sibillini Mountains

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Keywords: Debris flows hazard, Cartography, Sibillini mountains

Recent studies on debris flows of the Sibillini Mountains area (Farabollini, 2005; Materazzi, et al., 2010) have provided a check on the main related predisposing conditions: lithostratigraphic setting; bedrock bedding (jointing; frequent layering; alternating lithologies), major tectonization, large amounts of coarse and poorly sorted material (debris, landslides, moraines, etc.); water (snow, ice, surficial aquifers, springs, etc.).

As part of the activities related to the collaboration between AIGEO and Ispra, a review of the Geomorphological Legend predisposing the CARG Cartography (SGN, 1994) with a focus on the hydrogeomophological hazard, it has been proposed.

However the opportunity to represent the debris flows hazard in the geomorphological mapping assumes a very important meaning in order to the land planning: through symbolism and graphic elements are therefore represented significant features that influence the occurrence and the propagation of a debris flow event, considering too its activities in a deterministic and probabilistic key for its occurrence and propagation. The state of the activity of the process, the frequency of the events, the jointing and tectonization of the rock originating the debris, are important informations in order to understand the active phenomenon and to hypothesize its evolution.

The present proposal derive from a detailed geomorphological survey (1: 10,000 scale), regarding a portion of the Sibillini Mountains, and wants to improve the representation of elements and information that otherwise would not find space in the "classic" geomorphological legend: elements and informations actually very useful in land planning in order to risk prevention and planning interventions related to the safety of the territory.

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Geomorphological mapping in urban area: changes in stream network of Genoa historical city (Liguria, Italy)

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Keywords: urban geomorphology, stream modifications, human impact, geo-hydrological risk.

All over the centuries the expansion of residential, industrial and harbour settlements of Genoa city have impacted on geomorphological processes along the narrow coastal plains and surrounding slopes. Mostly the drainage network has been strongly modified by rectification, diversion and culvert interventions, causing critical flow section reductions (Limoncelli & Marini, 1971; Brandolini & Sbardella, 2001). These morphological changes resulted in increasing geo-hydrological hazard and, consequently, Genoa municipality has been affected by even more recurrent floods (Brandolini et al., 2012; Faccini et al., 2015).

This research focuses the attention of Genoa Old Port and surrounding area - where historically town developed - with the aim to reconstruct the former stream network, culverted since Middle Ages and currently almost totally underground. The final goal is to perform a G.I.S. based geomorphological map applying the proposal of legend in testing progress within AIGeo.

The study is based on comparison among ancient and recent maps, aerial photointerpretation, historic archives data, geotechnical investigations conducted for engineering purposes and field survey.The area, with an extent of about 8.5 km^2, is characterized by several catchments, from W to E: San Bartolomeo (0.49 km^2), San Lazzaro (1.33 km^2), San Teodoro (0.54 km^2), Lagaccio (2.36 km^2), Sant'Ugo (0.8 km^2), Carbonara (1.1 km^2), Sant'Anna (0.72 km^2) and Torbido (1.17 km^2). These watercourses, modified over time in channels and nowadays with a man-made hydraulic network catchments, flow culverted under the streets of the old town (Bixio et al., 2015).

A more detailed knowledge of these underground streams could contribute to a better evaluation of geo-hydrological hazards and planning of risk mitigation measures for supporting Basin Master Plan of Genoa metropolitan area.

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The new ISPRA-AIGEO object-based geomorphological mapping model

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Keywords: Geomorphological mapping, Hazard assessment, Risk mitigation.

Geomorphological mapping is currently present in practically all land management and geo-hazard zoning projects and is increasingly spreading to other fields such as hydrology, hydraulics, pedology, forestry, agronomy and geo-archeology. However, despite this great potential for use, the "traditional" symbol-based mapping approach seems no longer entirely suitable to adequately describe the complexity of physical landscape at different scales and, in particular, provide dimensionally correct data to be applied in various territorial issues. In order to meet this requirements, the ISPRA-AIGEO Working Group, has developed a new full coverage, hierarchical, multi-scale, object-based mapping model, in which the spatial properties of landforms are reproduced in a precise and repeatable way, reducing the use of map symbols in favor of properly delimited surface entities (objects), represented as closed polygons, open lines and point symbols, each of which accompanied by a table of attributes. This model finds its maximum expression in the screen visualization, where it is possible to select the surveyed data and interrogate them to learn about the associated attributes. A mapping model like this is today possible thanks to the recent advances of remote sensing techniques and the availability of new media such as GPS, high resolution DTM and GIS. More in particular, the methodology is articulated in the following points: 1. construction of a “traditional” field surveyed geomorphological map sided by data sheet filling of landform attributes, together with a technically oriented litological map at the same scale; 2. implementation, in a GIS environment, of the conceptual model of object-based map in a structure containing all the different geomorphological entities and their mutual, uniquely defined relationships, organized according to an ontological criterion; 3. inclusion in the database of the primitive graphics, and splitting the investigated area into geomorphological objects by high resolution DTM analysis; 4. definition of a hierarchical taxonomy of "topologically nested geomorphological entities" supported by upwards/downwards scale-transition rules to allow landform generalization and decomposition, where requested. The new object-based mapping model will be applied experimentally in the realization of a 1:50,000 geomorphological sheet and, subsequently, will be disseminated within the scientific and professional geological communities by means of special publications and intensive updating courses.

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Object-based Geomorphological Mapping: application at basin and event scale, as support to shallow landslide hazard assessment

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Keywords: Geomorphological mapping, floods, landslides, geomorphological hazards.

Floods and landslides events are part of the geomorphological hazards. Geomorphological approaches includes the survey, mapping and modelling of Earth's surface processes and related landforms that cause hazards in different space-time scales. The main issue is to perform evolutionary hillslope scenarios to predict geomorphological hazards. The object-based geomorphological mapping system (GmIS_UniSa), previously illustrated in Dramis et al. (2011), provides geomorphological modelling framework and tools to better represent and predict landslide scenarios. The geomorphological model is structured by a set of landforms, identified by applying specific 4-D geo-morphometric procedures, recently implemented in the GmIS_UniSa (Guida et al., 2015). Event landslide maps, as representation of evolutionary scenarios, are the result of analysis of the space-time geomorphological model that is stored in the mapping system. The evolutionary scenarios are the results of association of landslide dynamics with space relations between geomorphological objects (landforms), corresponding to time relations. Such a landslide evolutionary map shows not only where successive landslides were triggered in the headwaters, but also where their scared channels and ravines, travelling downslope, and successive depositional landforms found along the piedmont. Likelihood of landslide event map, jointly with the occurrence of a triggering event, applying one of the available distribute stability analysis, can provide a more reliable procedure than others, so-called "quantitative" approaches (i.e. "map unit", without evolutionary meanings) to define landslide hazard map. The study area is the Calvagnola basin in Campania region, southern Italy, where the main geomorphological hazard is related to shallow flow-like landslides affecting the pyroclastic and colluvial deposits on step hillslopes with limestone bedrock.

Dramis F., Guida D. & Cestari A. 2011. Nature and Aims of Geomorphological Mapping. In M. J. Smith, P. Paron, J. S. Griffith Geomorphological Mapping: Methods and Applications: A Professional Handbook of Techniques and Applications (Developments in Earth Surface Processes), 39-73, Elsevier.

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Coastal Morphodynamics AIGeo-WG: new geomorphological legend of the Italian coast

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Keywords: coastal geomorphology, geomorphological mapping, Italian coast.

In the last years, the activities of the AIGeo (Italian Association of Physical Geography and Geomorphology) Working Groups (WGs) were aimed at the new issue of the legend of the Italian Geomorphological Map.

The activities were performed keeping in mind these necessities:

- to add new symbols because of the great progresses made in geomorphology in terms of new knowledge on geomorphological processes and landforms, especially after the first issue of the legend in 1994;
- to have a legend that is usable with large scale maps, suitable for applied purposes;
- to create a legend usable with softwares (GIS environments, etc.).

The WG on Coastal Morphodynamics contributed to this work, as well, promoting, through meetings and workshops, the debate among the Italian coastal geomorphologists on the approach needed to produce a modern geomorphological legend. The classic dichotomy forms-processes, widely used in the geomorphological mapping, is often based on static concepts, especially when applied to marine and coastal areas, affected by fast dynamic events, sometimes paroxysmal.

We present the new geomorphological legend to represent both coastal and underwater contexts, aimed to the improvement of classic geomorphological legends.

The main goal of the work was the production of a legend suitable to clarify the importance and the need of representing landforms in the context of the Quaternary evolution, as well as of the more recent processes.

The geomorphological map of the floodplain of River Taro (Northern Apennines) as tool for flood hazards assessment

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Keywords: flood hazards, geomorphological mapping, River Taro, northern Apennines.

In the last years, the northern Apennines have been stricken by some extreme meteorological events characterized by intense rainfalls fallen in few hours. These events caused a large number of debris flows and small landslides in the higher part of hydrographic basins (1st to 3rd order streams) while the flood plain of the major torrents (4th to 7th order streams) underwent bank erosion and flooding processes damaging buildings, bridges and roads.

The integrated use of classic geomorphologic tools, like a geomorphological map and aerial photographs, together with high resolution LIDAR allowed us to recognize and mapping the parts in the plain of River Taro subject to flood hazards.

The floodplain of Taro River is an intense populated area with many settlements, human structurers and craft areas. The flooding areas with different recurrent time (floods with a time of recurrence of 30-50, 100-200 and 500 years) were recognized mainly with a geomorphological and hydraulic integrated approach. This work is a contribution for the definition of flooding areas of the rivers combining high resolution hydraulic and geomorphologic data.

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Object-based Geomorphological Mapping: application at basin and event scale, as support to urban planning

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Keywords: Geomorphological Mapping, land use planning, urban development.

Geology model act as basis for planners and engineers for rational land use planning and urban development. Data sources representative of lithology, seismic-induced effects, morphology, hydrology, flooding and landslide susceptibility were combined to produce geological land use maps. Urban geomorphology is the surface component of geology model and is the process that change the cityscape or natural terrain. There is a need to understand the dynamic interaction between the man activity and the geomorphic processes of the urban area. The main issue is to perform evolutionary scenarios to predict interaction with urban plan. The object-based geomorphological mapping system (GmIS_UniSa), previously illustrated in Dramis et al. (2011), provides geomorphological modelling framework and tools to better represent and predict evolutionary scenarios in the cityscape or natural terrain. The geomorphological model is structured by a set of landforms, identified by applying specific 4-D geo-morphometric procedures, recently implemented in the GmIS_UniSa (Guida et al., 2015). Geological land use maps, as representation of evolutionary scenarios, are the result of analysis of the space-time geomorphological model that is stored in the mapping system. Currently geological land use maps resulting from overlay of base maps. An example can be the Seismic Microzonation map, as a result of overlay of lithology and geomorphology. In the GmIS_UniSa mapping system, geological land-use map is the results of the landform (object) properties (proximity, superimposition, lithology) analysis. The study area is the Eboli municipality in Campania region, southern Italy.

Dramis F., Guida D. & Cestari A. 2011. Nature and Aims of Geomorphological Mapping. In M. J. Smith, P. Paron, J. S. Griffith Geomorphological Mapping: Methods and Applications: A Professional Handbook of Techniques and Applications (Developments in Earth Surface Processes), 39-73, Elsevier.

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Geomorphological hazard and cultural heritage in the southern Sinis peninsula (Sardinia, Italy)

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Keywords: Sardinia, Geomorphological hazard, mapping, cultural heritage.

The scientific importance of the Sinis peninsula (central western Sardinia – Italy) inheres in its many and different fields of interest, mainly geological, geomorphological and archaeological. The geological contest of the southern peninsula is characterised by a stratigraphic succession composed of clays and silt of the middle Miocene, laying in unconformity with Messinian limestones and marls, Pliocene sandstones and conglomerates overlay the Miocene sequence, between the two occurs an unconformity contact. The series is closed by basaltic volcanic, arranged into different flows. The Pleistocene sequence is, in this area, particularly complete and represented by sediments related both to intertidal and emerged low energy beach environments and lagoon environments (MIS 5.5), and, towards the top, a progressive transition to more frankly continental environments, with, at the roof, deposits of eolic sandstones relating to the regressive phase (MIS 4/2). The slopes instability processes are strongly controlled by the structural lineation dislocating the different sectors of the peninsula and by the lithological sequence and unconformity contacts, in particular between the Miocene marls and the Messinian limestones. Many different kind of landslide are present all over the area, involving also the many archaeological sites, first of all the Phoenician-Punic city of Tharros. Along the southern-western side of the peninsula, which is exposed to the dominant and regnant winds, many episodes of rotational and block landslides occur, controlled by sea erosion.

Here extreme high-energy meteomarine events may occur, recording wave heights of more than 10 meters with an annual energy of 130/150 GN m/m. Different kind of landslides involve different lithology, in particular we observe planar and rotational slides on Miocene series and block falls and topples on Pliocene basalts and Pleistocene eolianites. The southern Sinis peninsula represents an area where the interest of researchers and the natural touristic vocation runs parallel.

With the present work we want to propose a detailed geomorphological map addressed to assess the risk factors threatening the cultural heritage present in the territory.

Survey data had been compared with the air photo interpretation and with the DTM at high resolution. Software GIS Global mapper and Arcgis were used with this purpose. It had been possible to recognize the different kind of movements and the succession of landslides that involved parts of Tharros and the necropolis. These data are indispensable for future plans having to do with archaeological heritage preservation.

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Reconstruction of 3D models by historical aerial photos for geomorphological investigation

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Keywords: SfM, aerial images, geomorphology, 3D reconstruction, historical data.

The geomorphological evolution of a territory, also connected with the climate change, is fundamental to analyze the hazard and risk mitigation assessment. In the last decades the increasing technological progresses in the observation of Earth surfaces have enlarged possibilities to detect and monitor geomorphological processes also by the development of remote sensing methodologies, such as the use of Persistent Scatterers or change detection techniques. However, the possibility to reconstruct back in time a time series is a challenge for analyzing a long-term evolution. In such a sense, the use of historical aerial photographs, taken since the early 40s of the last century, appears relevant to study environmental evolution (e.g. Carrara et al., 2003).

Non-digital old aerial photos have only provided up to now 2D information and their 3D analysis was routinely obtained through stereoscopic techniques. In this research, the applicability of SfM (Structure from Motion) technique (e.g. Westoby et al., 2012; Fonstad et al., 2013) for studying geomorphological evolution of Earth surface by 3D models based is examined. 3D models of different test areas were reconstructed by processing historical aerial images by means of the software Agisoft Photoscan. Although, it is well known that SfM technique usually requires a considerable number of digital images, the challenge of this work is to reconstruct 3D models using a reduced set of non-digital aerial photos. It was demonstrated that the obtained 3D models allow the study of the evolution of geomorphological features over wide areas. These models can be exported to other software and compared with new web services (e.g. Web Map Services or Google Earth) in different ways, e.g. point clouds and georeferenced images. In this paper, four test areas were studied: a region in southern Italy affected by landslides; a badlands area in central Italy; a coastal zone and a sector of northwest Italy with an open-pit mining activity.

The findings of this study suggest that despite some disadvantages arisen during its application, the SfM technique shows promising results in recognizing geomorphological features, investigating the temporal and spatial evolution of Earth surface and in analyzing the effect of different anthropic activities, thus providing a global vision of the territory.

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The new Geomorphological Map of Italy: a proposal morphostructural legend

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Keywords: Geomorphological Mapping, Morphostructural Legend, Natural Hazards.

On behalf of the ISPRA-AIGeo Commission for the new Geomorphological Map of Italy, established since 2014, the Working Groups of the Italian Association of Physical Geography and Geomorphology (AIGeo) took in charge the update of the Geomorphological Legend. Here, we propose a new scheme of the morphostructural section of the Legend, as implemented by the Working Group of Structural, Tectonic, and Volcanic Geomorphology and shared with the institutional Commission. This proposal includes a significant increase in the number of adopted symbols, grouped for the first time in three different categories related to litho-structural, tectonic, and volcanic landforms. The litho-structural landforms have just to be meant as passively controlled by geological structures. They are the result of direct expression of those structures or driven by exhumation and morphoselection processes, whereas the tectonic ones are the morphological effects of the recent or active deformation. Moreover, we include a large review of the morphotectonic evidence produced by different surface processes (as discussed and shared with the other WGs).

The new morphostuctural legend contains most of the landforms already included in the 1994 official geomorphological legend (Brancaccio et al., 1994), updated by D'Orefice & Graciotti (2015), and several new landforms with new related symbols. The significant increase of symbols is justified by the multiscalar approach adopted in the new cartographic project. Such an approach was developed in the perspective of a new relational geodatabase to be structured according to the EU Legislation (INSPIRE Directive).

The layer overlapping of landforms and different bedrock units, also related to weathering and fracturing conditions, is still an open question debated among the different WGs. Some of the new symbols have been selected from maps realized using GIS databases and already published by components of the WG, whereas the others are here proposed for the first time.

The new legend has the aim of supporting the natural hazard evaluation especially through real time updating of the geodatabase, to meet the demand of a larger usability by public agencies and private contractors in environmental land management.

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Deep-seated gravitational deformations, investigation methods and associated hazard

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Keywords: DSGSD, Investigation methods, Hazard.

Deep-seated gravitational deformations (DSGSD) are large-scale gravity driven mass movements, commonly widespread in recently uplifted mountain ranges. Their origin and evolution are controlled by several factors, among which structure, relief, tectonics and seismic activity play a primary role (Dramis & Sorriso-Valvo, 1994). The deformation occurs by creep, with extremely slow rates, at times interrupted by short-lived acceleration stages, often induced by earthquakes or, more rarely, by extreme rainfall events. The most common typologies are: *bilateral spreads* (horizontal extension of a relief with formation of double ridges at its top and, sometimes, shear planes at its base); *lateral spreads* (involving thick rocky masses horizontally overlying softer materials on top of a relief); *deep-seated block slides* (characterized by relatively small translational displacements of thick stiff blocks overlying low sloping soft layers); *sackungs*, also known as *gravity sags* (preparatory stages of huge rotational rock slides, that in most cases are unable to reach the final collapse) (Dramis et al., 1995). These latter present the following geomorphic features: absence of a continuous shear surface; graben-like depressions and counter slope scarplets in the upper part of the slope; and compressional features, such as bulging and low-angle shear planes, in its lowermost portion; evolution influenced by the interaction between gravitational stress and active/residual tectonic stress. Besides field work and air-photo analysis, the most applied investigation methods include: LIDAR survey to describe in detail the geomorphological features of the slope; high resolution SAR interferometry to point out the occurrence of even extremely slight slope movements; finite-element models of the deformed mass to highlight the stress field pattern; paleo-seismological analyses to correlate past earthquakes and acceleration steps of the deformation. Different levels of hazard are associated to the different types of DSGSD: very low levels to *bilateral spreading*; low to high levels to *lateral spreading* and *deep-seated block sliding*, which can cause deformation on the moving mass surface and landslides on its edges; very high levels to *sackungs* in case of possible collapse, considering the huge mass involved and the extreme rapidity of the event. Other hazards concern landslide triggering from the deforming slope and disturbance to surficial and underground construction works.

Dramis F., Farabollini P., Gentili B. & Pambianchi G. 1995. - Neotectonics and large-scale gravitational phenomena in the Umbria-Marche Apennines, Italy. In: O. Slaymaker (ed.) - Steepland Geomorphology, J. Wiley & Sons, Chichester, 199-217.

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DSGSD developed along the Cenischia-Nizza tectonic system in the Rodoretto Valley (Western Alps)

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Keywords: Western Alps, deep seated gravitational slope deformation, fracture system.

The Rodoretto Valley, a left tributary of the Germanasca Valley, is located in the Western Alps (NW Italy) from 1200 m to 2900 m a. s. l. This area is shaped by glaciers, and subsequently by watercourses, in the Greenstone and Schist Complex (Penninic Domain), near the N-S tectonic contact with the Dora Maira Massif. The Rodoretto Valley is extensively involved by deep seated gravitational slope deformation (DSGSD), responsible for developing of many gravitational morpho-structures (as doubled ridges, minor scarps, trenches) and landslide accumulations (Forno et al., 2012; 2013). The deep-seated gravitational slope deformation effects on the Quaternary sediment facies and distribution were particularly investigated.

The main conditions that favoured the DSGSD evolution are:

- high relief energy;
- strong shaping by glaciers;
- great deepening by watercourses;
- bad geomechanical conditions of the bedrock, characterized by a high fracturing degree.

Research was conducted through the traditional geological survey, with high detail, and using also geomatics techniques in order to produce a geological and morphological map. UAV (Unmanned Aerial Vehicle) flight was carried out for DSM (digital surface model) images generation, combined with topographic surveys of terrain employing total station and GNSS (Global Navigation Satellite System) instruments for georeferencing the images. These geomatics techniques had greatly helped in the detailed geological mapping in largely inaccessible areas.

The combined geological and geomatics surveys lead to suppose that the critical geomechanical conditions of bedrock are strictly related to the crossing of two major tectonic discontinuity systems with N-S (Cenischia-Nizza System) and NNW-SSE trend respectively, suggesting a link with the active tectonics. The distribution of many structural and morpho-structural elements suggests the presence of sliding surfaces connected to the DSGSD, that can probably lie below the current Rodoretto Valley floor, as a result of the great deepening of the main Germanasca Valley.

DSGSD susceptibility is a mix of predisposing factors reducing the slopes stability. The major factors that influence the DSGSD processes are represented by slope gradient and rainfall aggressiveness (Taddia et al., 2015). The knowledge of the interaction among the predisposing factors may provide powerful information about the location of likely future landslides phenomena, essential for land planning.

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Geomorphological mapping of mountain regions: examples of a new GIS-based approach in the Western Alps

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Keywords: geomorphographic mapping, geomorphometry, DEM, Western Alps.

A new GIS-based, full-coverage, geomorphological mapping method has tested in the Western Alps (Piemonte and Valle d'Aosta Regions, Italy). A concept of pattern-based analysis of land-surface has been developed, where a basic unit of analysis is a pattern of landform elements. Our aims is to enhance geomorphological mapping as crucial tool for recognition and assessment of landforms and processes of the dynamic environments of the Alpine region.

We collected information on topography and slope steepness, characteristics of surface materials, past, recent and present day geomorphic processes such as glacial advances and retreats, slope instabilities and fluvial/torrent dynamics.

Our goal is to portray the landscape as a mosaic of irregularly shaped areas, which are referred to as polygons.

GIS-integration of data allowed localization of preferred areas where local climate conditions, glacial dynamics, tectonic and geomorphologic settings strongly interact each other for producing movable materials and unstable slopes. In the first step we performed the automatic delineation of physiographic units: the DEM has been automatically subdivided into morphometric units. Each extracted polygon has been reclassified following a geomorphological approach, and renamed as geomorphographic units.

These geomorphographic units have been defined with a common morphometric classification (flat on tops, slope and scarps, flat and terraces, flat in low positions, etc.) coupled with geomorphological process evidences recognized in the study area.

Further analysis on geomorphographic units yielded to obtain other geothematics layers, such as: geomorphodiversity, within mapped landforms of relevant geoheritage value; morpho-tectonic, concerning the structural evolution; debris cover of glaciers, for multitemporal analysis of historical archive data, maps and aerial imagery.

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Objective Geomorphological Mapping at Capo Licosa (Cilento Global Geopark, Italy)

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Keywords: Geomorphological Mapping, Cilento, UNESCO Global Geopark.

Following the GmIS_UniSa procedure (Dramis et al., 2011), object-based geomorphological mapping has been carried out on the Capo Licosa area (Cilento, UNESCO Global Geopark) aiming to recognize the hierarchical arrangement of the outcropping geomorphological entities and reconstruct the spatial superposition and temporal succession of landforms. The study area, well known by traditional geomorphological analysis, is characterized by remnants of Pleistocene morphogenesis such alluvial fan complexes, marine terrace staircases and headwater landforms produced by diffusive processes (hollows, side-slopes and noses). All these features are affected by Holocene denudation/deposition processes, such as landslides, retreating cliffs, gullying and sapping erosion. The GmIS_UniSa object-based spatial analysis demonstrated its capability to perform not only 3D landform recognition and representation, but also a 4D reconstruction of geomorphic events in polygenetic and poly-chronologic landscapes. In particular, the analysis of to the zero order basins (Guida, 2003) showed an effective capacity of understanding the time-space relationships of landforms in the object-based mapping approach. Detailed fieldwork confirmed the consistence between the geo-morphometric signature of landform distribution and their long-term evolution, revealing a mid-term geomorphic competition at the hollow toe, between gully retreat and colluvial filling by soil creep from side slopes. Moreover, the topological relations of superposition and substitution between geomorphological objects, introduces the perspective of transforming the present-day object-based mapping into event-based mapping. This will allow a 'non-subjective' and repeatable definition of landform changes in order to better pursue dynamic landscape analyses and support evolutionary scenarios, useful for the assessment of geomorphological hazards.

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GIS-based geomorphological map of the Calore River alluvial plain near Benevento (southern Italy) overflooded by the 15th October 2016 event

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Keywords: Geomorphological mapping, GIS, floods, hazard, risk, Calore River, Benevento, Southern Italy.

Geomorphological maps play a fundamental role in mitigation of flood hazard and risk (Rinaldi et al., 2015; Magliulo & Valente, 2014). Classical geomorphological maps are nowadays generally replaced by GIS-based information layers. Using GIS, the space can be described by a series of "objects" discretized by points, lines or polygons (Dramis et al., 2011). Examples of GIS-based geomorphological maps of alluvial plains are provided, among others, by Valente & Magliulo (2012) and Magliulo & Cusano (2016).

On 15th October 2015, the alluvial plain of the Calore R. underwent a destructive flood, with an increase of the river water level up to 10 m (Valente et al., 2016). In this paper, we describe the GIS-based, full coverage, object-oriented geomorphological map of the overflooded sectors of the Calore R. alluvial plain in the Benevento area. The map is the graphical representation of the results of a geomorphological study, that was carried out by introducing and analyzing into the ArcGIS 9.3 software: (a) 1:50,000-scaled historical topographic maps from 1870, 1909, 1936; (b) 1:25,000-scaled topographic maps from 1955; (c) 1:10,000 nominal-scaled orthophotos from 1998; and (d) 1:5,000 nominal scale orthophotos from 2011. Positional errors ranged from about 30 m to less than 3 m. The detected landforms were checked during a 1:10,000 geomorphological field survey.

The alluvial plain was characterized by abandoned channels, anthropic landforms and several orders of river terraces, separated by strongly weathered, reshaped, very gently sloping and inactive fluvial scarps less than 1 m high. The proposed map could be a fundamental tool for a correct flood hazard assessment, which could avoid or reduce the negative effects of events such as that of the 15th October 2015.

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Geothematic maps as a supporting tool for the choice of engineering works in complex volcanic cliffs: the Ponza case study, central Italy

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Keywords: Landslide susceptibility maps, coastal rockfalls, Ponza island, Italy.

The island of Ponza belongs to the Pontine Islands, located in the Gulf of Gaeta (Latium region, Central Italy). It is almost completely made up of volcanic products, deriving from two different magmatic associations starting from the Lower Pleistocene, in turn characterized by rhyolitic-rhyodacitic and trachytic products, respectively.

The present-day geomorphological setting at Ponza is the result of interactions among the lithological features of the volcaniclastic cemented and loose rocks, the various volcano-tectonic events and the weathering processes, the latter caused by the exogenous agents (sea wave action, wind abrasion and erosion due to runoff and infiltration water). All the above processes, combined with the lithological characters of the rocks, favour the development of instability phenomena, affecting both the rocks and the loose deposits.

At a greater detail, the rock masses, showing well-developed joint systems and landforms produced by differential erosion, are involved in rockfalls, which locally may even reach large size. The debris and infilling materials covering the volcanic bedrock, on the other hand, are affected by shallow slides and flows, mostly triggered by intense rainfalls. Long stretches of the coastline, where in the past an intense quarrying activity was carried out, show nowadays rock cliffs produced by the anthropogenic activities, which present instability features similar to those affecting the natural cliffs.

The diffuse erosional processes, and the frequent slope movements, represent the main factors of risk for the local population, as well as for the tourists, which occupy during the summer season the long stretches of beaches bounded by rock cliffs.

In such a setting, i.e. an island where tourism plays a crucial role in the social-economical activities, production of landslide susceptibility maps is a fundamental step in the process of risk mitigation, through identification of the priority areas where to concentrate the first and necessary engineering works.

Here a methodology for the rapid production of landslide susceptibility maps is described, based upon a geological and geomorphological criterion, and tailor-made for complex geological settings characterized by presence of loose deposits and hard rocks, and by several different landforms, including some of anthropogenic origins as man-made cavities.

Beside obtaining a zonation of the areas most susceptible to slope movements, such an approach allows:

- to define intervention priorities, based upon the elements at risk therein present; and,
- to choose, and to properly design (also in terms of an economic estimation of the costs), the most feasible surveys and engineering stabilization works, of both the active and passive types.

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A comprehensive morphotectonic image of the Tyrrhenian Back-Arc Basin

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Keywords: EMODnet, morpho-analysis, tectonics.

Several geological and geophysical studies have been carried out in the Tyrrhenian Sea in order to reconstruct the origin and the evolution of the Tyrrhenian back-arc basin (Mediterranean Sea). This large region can be divided in four main geodynamic settings (Marani et al., 2004): 1) the northern Tyrrhenian province, delimited by the Tuscan Archipelago, the Baronie Seamount and the Pontine Islands; 2) the eastern-passive Sardinia margin, located between the Baronie and the Cornacya Seamounts; 3) the active Appenninic margins of the southern and eastern Tyrrhenian; 4) the ocean floored deep basins, where the Vavilov and Marsili volcanoes and related abyssal plains are located.

The aim of this work is to obtain an updated structural interpretation of the Tyrrhenian back-arc basin at a regional scale. A full-scale image of the Tyrrhenian back-arc basin was created to perform the morphotectonic analysis of the sea-bottom features. Several major morphotectonic lineaments, as escarpments and elongated basin axes, allowed us to divide the Tyrrhenian Sea in six main zones, each characterized by different trends and stress fields. Based on this new morphotectonic map, the opening and evolution of the Tyrrhenian back-arc basin may have been more complex than generally assumed.

This work has been realized in the frame of cooperation between Geological Survey of Italy-ISPRA and ISMAR-CNR of Bologna, aimed at the production of deliverables for the EMODnet Geology 2 Project. EMODnet (European Marine Observation and Data Network) is a programme supported by the European Commission, Directorate General for Maritime Affairs and Fisheries (DG MARE). Multibeam bathymetry data (200 m scale) have been downloaded from the EMODnet website (http://www.emodnet.eu/) whereas contours (100 m scale) have been obtained from Marani et al. (2004).

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Geomorphological map of Mt. Pruno southern slope, Roscigno, Cilento, Vallo di Diano and Alburni Geopark

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Keywords: geomorphological mapping, landslide, Cilento.

This work refers the application of the method proposed by Dramis et al. (2011) to the gravitational phenomena mapping that affect the southern slope of Mount Pruno, the highest peak of the Roscigno municipality (Cilento, Vallo di Diano and Alburni Geopark) as operative contribution to the geomorphological mapping applied to landslide risk management end their mitigation on hilly area on structurally complex terrains.

The Mount Pruno area is located in the upper section of the Calore Salernitano river basin; this area is characterized by the outcropping of terrigenous formations defined "Internal Units" (Cammarosano et al, 2004) which promote the establishment of a complex deepening hydrographic network from at least Early Pleistocene (De Riso & Santo, 1997). This peculiar geomorphological setting favours big landslides processes on the slopes with intermittent and long-term evolution.

This representation can be considered a hierarchical and a multiscale mapping: once a focal level (scale) it's been established, it's possible to move to a larger or a smaller scale by polygon decomposing or generalizing operations; in this nested sequence each hierarchy level summarize the effects of the lower levels (Dramis et al, 2011).

The recognized landforms were hierarchically classified as:

- **Landslide system**: includes landforms related to the same morphogenetic process and produced by multiple events (scale 1:25.000), focusing on a landslide system, it can be considered as a set of heterogeneous landslides (in terms of type, age and state of activity) which evolves within the same morphological unit (Guida et al, 1995);
- **Landslide complex**: includes landforms related to the same morphogenetic process, produced by single or multiple events that have the same evolutionary style (scale 1:10.000);
- **Landslide and landslide components**: includes landforms related to a single morphogenetic process and produced by a single event or not further decomposable (scale 1:5.000).
- The focal level adopted for this work is the scale 1:5.000, by generalization two further levels were obtained (1:10.000; 1:25.000).

This method, applied to a detail scale (> 1:5.000) allows the definition of the areas affected by a given morphogenetic process (such as landslides) univocally, which, integrated with a depth value, define volumes: starting from this and through the interoperability of the GIS-based softwares, geomorphological maps becomes a source of data essential for regional planning and hazards mitigation.

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The extreme rainfall event of September 2015 (northern Apennines) in Trebbia-Nure-Aveto streams drainage basins: geomorphological mapping of ground effects for the analysis of debris flows hazards

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Keywords: Extreme rainfalls, debris flow, geomorphological mapping, northern Apennines.

Recently, meteorological events characterized by intense rainfalls fallen in few hours have been damaged the hilly and mountainous territory of Emilia-Romagna Region. Several types of effect on the ground: i.e. debris flows, shallow landslides and overbank flooding occurred, highlighting the vulnerability of this territory.

In details, during the night between 13th and 14th September 2015 intense rainfalls damaged the area between the valleys of Trebbia, Nure and Aveto streams, between Emilia-Romagna and Liguria in the northern Apennines. During this rainfall event 300 mm of rain, roughly, fell in 6 hours. During the first part of the storm, several rain gauges of the ARPA-SIM network recorded rainfall peaks over 100 mm/hr.

The mapping of the processes caused from the rainfalls on the ground was quickly acquired thanks to the airborne and satellite imageries acquired by the Emergency Management Service (E.M.S. emergency.copernicus.eu), within the framework Copernicus of EU Commission, realized with the support of European Spatial Agency (E.S.A.). The processing of maps of ground effects allowed to have maps of damages useful during the successive emergency phase (several days long after the event).

After the emergency phase, there was the possibility to validate the geomorphological data acquired through fieldwork.

The storm caused about 100 debris flows that were the main cause of damage on man-made structures. The most damages were observed in correspondence of alluvial fans that represent for the area the privileged site of settlements.

The analysis of historical database allowed the mapping of areas characterized by potential hazards and risk due to debris flows in Emilia Romagna that is characterized by 27% of hills and 25% of mountainous territory.

GIS-based physiographic unit mapping for the ecoregional classification of Italy.

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Keywords: physiography, hierarchical approach, multiscale process, land unit mapping.

Aim of this study is to illustrate the GIS-based mapping of the physiographic units performed to define the ecoregions of Italy, by means of an ecological classification of land. Physiographic mapping was based on a methodological process that is hierarchical, multiscale, authomatic grid-based and supervised by expert-orientated rules (Dramis et al., 2011). Accordingly, the physiographic units proposed by Blasi et al. (2011) were used for the hierarchical ecological regionalisation of Italy in *Divisions, Provinces, Sections, Subsections, Land systems and Land facets*. Physiography, intended as regional-scale geomorphology, played a minor role at the *Division* level, while was considered diagnostic when defining *Provinces*. The *orographic systems*, as spatial expression of geotectonic setting and lithological control, allowed a simplification of the composite geomorphological pattern of Italy posed by Alpine and Apennine orogenesis and morphogenesis (Cuomo et al., 2011). Boundaries between Italian *Provinces* reflected significant differences in dominant lithological bedrock, general morphological setting, relief energy, which varies between different orogens and hydrographic pattern as expression of hydro-meteorological regime. As for *Sections* and *Subsections* the informations used to assess the occurrence of the main lithological and morphological systems have been subsequently related to different depositional environments at particular geographic locations and was supplemented with more local contributions. With regard to *Sections*, we took into account the physiographic complexes (lithostructural regions), whereas for the *Subsections* the morpho-tectonic sectors were used. The litho-morphological classification recently produced for the whole country (Smiraglia et al., 2013), represented the basic information for the physiographic distinction between *Land systems*, according to diagnostic lithology (Effusive igneous, Intrusive igneous, Metamorphic, Carbonate sedimentary, Chemical sedimentary, Clastic sedimentary, Terraced clastic sedimentary, Terrigenous sedimentary), and *Land facets* according to diagnostic geomorphology (Coast, Plain, Piedmont,Tableland, Hillslope, Summit and Valley).

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Morphotectonic map of the Pescara River Valley

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Keywords: Adriatic piedmont, Quaternary landscape, alluvial terraces, drainage evolution.

This paper presents the Morphotectonic map of the Pescara River Valley (scale 1:40,000). With SW-NE direction in the Adriatic piedmont of the central Apennine (Abruzzo Region, Italy), the Pescara River connects the drainage system of the outer Apennine chain (e.g., Sulmona and Tirino intermountain basins, Aterno longitudinal valleys) with the Adriatic sea, playing a key role in the redistribution of continental sediments and, therefore, in the Quaternary landscape evolution of this region.

The Adriatic piedmont fringes the easternmost carbonate ridges of the chain (Maiella and Gran Sasso reliefs) and is characterized by a low relief hilly landscape (i.e., hogback, cuesta, mesa reliefs) carved on Mio-Plio-Quaternary terrigenous bedrock, related to sin-, late-orogenic phases, and by Quaternary marine regressive and continental deposits of post-orogenic phase. This piedmont marks the transition between compressional active tectonics domains towards east (Adriatic coast), and extensional active domains towards west (Apennine chain). The Quaternary tectonic signature and timing in the chain areas are well inferred due to the presence of hard rocks and by geological analysis of thick post-orogenic successions trapped inside intermountain basins, as well as paleosurfaces analyses. In contrast, poorly studies on post-orogenic sequences of the piedmont are present, and the role of tectonics in the landscape development is still debated.

This work is focused on the analysis of post-orogenic continental deposits and related geomorphic markers (i.e., fluvial terraces, morphotectonic elements) capable of supplying direct or indirect information regarding tectonic forcing on the landscape. The morphotectonic map has been implemented within GIS environment by means of geological and geomorphological field surveys (1:5,000 scale) preceded by photogeology analysis (scale 1:33,000). Geological survey, supported by analysis of boreholes, was focused on continental post-orogenic sequence mostly consisting of alluvial, fluvial and slope deposits. All the lithologies have been classified based on their depositional environment, according to the national mapping guidelines. Geomorphological survey was focused on the analysis of the morphotectonic elements such as valleys, fluvial/alluvial terraces, ridges, slopes, and hydrographic features, outlining the widespread presence of structural, fluvial, slope gravity landforms, and related processes.

The reconstruction of the plano-altimetric trend of terraces and their correlation with geochronologic data of the deposits allowed for providing a first definition of the Quaternary geomorphological evolution of the area. This evolution mainly results from the combination of alternating surface and morphotectonic processes (fluvial and slope processes, uplift, local tectonics).

SESSION S29

Geomorphological-hydraulic risk and human impact: analysis of the processes and solutions

CONVENERS AND CHAIRPERSONS

Corrado Cencetti (Università di Perugia)
Piero Farabollini (Università di Camerino)
Andrea Fredduzzi (Università di Perugia)
Marco Giacopetti (Università di Camerino)

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Analysis and characterization of historical and recent landslide dams in the Umbria-Marche Apennine area

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Keywords: Umbria-Marche, landslide dam, hazard.

As part of a project finalized to evaluate landslide dams hazard in Umbria (central Italy), an analysis of recent and historical events occurred in the Umbria-Marche Apennines and neighboring (on the boundaries with Tuscany, Emilia-Romagna, Lazio and Abruzzo) was carried out.

The aim of this analysis is to characterize the phenomenon of landslide dam, identifying the parameters (geometrical, geological, hydrological and hydrogeomorphological) that could, if properly combined, make it possible or not the occurrence of a landslide dam in the study area.

Available data are related to 49 cases of landslides that have interfered with the river dynamics. 35 of these leaded to the formation of a dam lake, totally occluding the riverbed – floodplain system (landslide dams s.s.).

The analysis indicates that over half of those 35 events (60%) involved the turbiditic sediments in facies of flysch (alternation of marls and sandstones) outcropping in the area; prevailing landslide types are slumps, slides, flows and combination between the previous (complex or composite landslides); 83% has a volume of material involved less than 5 million cubic meters; the total width of the floodplain affected by the damming does not exceed 200 meters in 86% of examined cases.

In 29% of the total cases, the formation of a dam lake did not occurred; in the remaining cases, 49% of them was naturally drained by overflow and progressive erosion of the threshold; in 46% of cases the dam has resisted, so as to cause the filling of the lake with sediments or its current persistence (in the most recent cases).

For the evaluation of the landslide dams hazard, two representative parameters for the examined cases were chosen: the landslide volume (which provides informations on magnitude of the landslide) and the area of the watershed outlet at the section of blockage (related to the stream power of the river, to its flow discharge and then to its ability to erode the natural barrier).

The data indicate that most of the landslides (97%) that have interfered with the stream, producing a complete occlusion of the riverbed – floodplain system and the formation of a dam lake are characterized by a high index ratio: landslide volume / subtended watershed area.

However, this condition appears to be necessary, but not sufficient to make certain the total occlusion: the values of this index, in cases of partial occlusion (i.e. without that the landslide has produced the formation of a dam lake), are extremely dispersed, which does not allow to use the same index to determine with certainty the possibility of total occlusion.

Other parameters (the most important: velocity of the landslide and width of the involved riverbed - floodplain system) play, obviously, an important role that has to be properly evaluate.

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Fluvial erosion and landslides processes affecting the pelitic bedrock in the riverbed: examples from middle-lower Marche-Abruzzi fluvial river

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Keywords: Bank erosion, Cracking, Flooding, Human impact, Adriatic River.

The recent flooding, as a consequence of climate change on a vulnerable territory made dramatically by excessive human activity and lack of maintenance, have allowed us to see how the intense erosion and deepening of the riverbed are substantially the result of human impact. This paper aims to provide new knowledge on issues related to the deepening of the river system and the morphological changes of the riverbed (bank erosion, widening of the river area, depth, etc.) in response to the anthropic intervention occurred along the stream and the consequent change in the liquid and solid flow.

The river deepening it has allowed the outcrop, in large part of the riverbed in the middle and lower valley of the Adriatic rivers, the clay bedrock; the characteristics of stability of the banks, which mainly depend on the physical-mechanical properties of the materials forming the same and their structural arrangement, vary during the floods. For low values of the flow rate, the portion at the top of the bank are in a state of partial saturation, with the presence of capillary fringe which results in the development of hydrostatic negative pressure which stabilize the bank even in the presence of coarse-grained soils; the increase of the level of the free surface of the current it generates a forward flow toward the shore, with the formation of a region of total saturation that reduces the stabilizing effect of the capillary tensions and results in erosion phenomena; the latter produce the removal of debris cover, if the bank consists of gravel and sand, or the "planar rupture" processes, if the bank is cohesive.

The collapse of the banks, in particular, is influenced by an appreciable extent also from the drying cycles and imbibition of the same banks; in particular, the high summer temperatures may produce phenomena of drying and surface fracturing with possible phenomena of detachment of fragments of the bank; furthermore, along the floodplains, the pumping of water from wells, particularly important especially in summer, it produces visible signs of soil cracking which lay the bedrock for further erosion.

Ultimately, the breakage of the banks: a) cause the detensioning with opening of new fractures; b) lay bare the ground leaving them exposed to weathering processes in sub-aerial environment. The combination of these effects produces new ruptures in a self-sustaining process.

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Simulation of Natural Hazard related to a severe flood event in a network of ephemeral streams

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Keywords: integrated natural hazard modeling, ephemeral streams, flood risk, runoff generation.

Ephemeral streams are shallow water flow ways typical of semi-arid areas, often characterized by karst soils. These streams are usually dry and show like valleys or creeks and sometimes are used for anthropic activities. Their genesis is quite controversial (Cristino et al., 2015) and their activations, in terms of water draining, are rare, however these normally correspond to extreme rainfall events. These may generate very large runoffs, thus constituting an important Natural Hazard. Runoff generation is a non-linear process, conditioned by manifold boundary conditions, like soil coverage, structures, geology and lithology, besides the rainfall event. Therefore, an accurate and detailed knowledge of the catchments of ephemeral streams is necessary. Moreover, models aimed at reproducing runoff through networks of ephemeral streams have to integrate runoff generation and routing towards streams, to the analysis of flows and overflows of streams (Doglioni et al. 2012; Berardi et al., 2013). Here, such integrated approach is applied to some catchments of ephemeral streams, in a semi-arid karst area of south Italy, close to the town of Ginosa, where a severe flood event occurred in October 2013, causing damages to buildings and 4 fatalities. Starting from the rainfall data, registered with a time step of 30 minutes, and given a medium resolution (8 m) digital elevation model, it is implemented the model of the occurred critical event into a 2D integrated hydraulic solver to reproduce the flow (Doglioni et al., 2015). The obtained results are consistent with soil erosion phenomena observed in the catchment and the water levels observed in the largest ephemeral streams. It is interesting that traditional do not account for a detailed analysis of flow generation, being these based on lumped models. Therefore, such model permits to evaluate the flood susceptibility related to runoff through networks of ephemeral streams, thus constituting a flood risk mitigation approach, in particular for urbanized areas.

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Cristino M.C., Doglioni A. & Simeone V. 2015. Notes on morphological characters of ephemeral streams in Apulia region, south Italy Engineering Geology for Society and Territory – Volume 3 River Basins, Reservoir Sedimentation and Water Resources; doi: 10.1007/978-3-319-09054-2_37.

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A multiple approach to support geo-hydrological risk mitigation pursued by the land reclamation authority (Gargano, Apulia)

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Keywords: hydrogeological risk, extreme events, landslides, floods, Gargano Promontory, Apulia.

The main scope was to provide technological and methodological innovation to the Consorzio di Bonifica Montana del Gargano (CBMG), the land reclamation authority of the Gargano Promontory, to support their responsibilities that ranges from mitigation of hydrogeological risk to water supply, mainly for agricultural purposes. It was pursued by a group of private enterprises, with the CNR-IRPI's Hydrology laboratory support, through the GarganoLab project "Integrated information system for land management, environmental monitoring and emergency alert", funded by the Apulia Region as part of "Living Labs" measures.

The attention was paid to the natural hazards mitigation, due to landslides and floods, particularly catastrophic, as in the most recent flood event, which occurred from 1 to 09/09/2014, and the drought effects.

The Gargano Promontory is widely steep karstic. Due to the high proximity to the sea, it is hit by particularly sudden and extreme meteorological phenomena; with these characteristics the river flow even if infrequent and of short duration, is very often lightning catastrophic.

The idea behind the initiative was to create an integrated system of all useful knowledge to the CMBG mission and integrated into a system, which includes a WEB GIS interface, useful for interrogation, the continuous updating and real time dissemination of news and warnings concerning risky situations. The system integrates the climate networks with gauges installed in critical areas, located on the basis of studies realized by the project landslide risk.

The use of the GIS tool has created the most comprehensive geo-database for the study's area, collecting all the useful information (climate, geology, hydrogeology, monitoring networks, transport infrastructure, vulnerable areas, etc.), and integrating this knowledge with layers arising from previous activities.

A specific layer was proposed and realized concerning all type of works, hydraulic works, aqueducts, embankments, erosion protection, reforestation, dewatering, reclamation, implemented by the CBMG, including at least the geographical location and extent (linear or areal) in order to offer a digital basic tool to manage the works life from the idea, to the realization and maintenance, in which work all relevant data can be contained and updated, including geometric, temporal (relating, for example, to the design, implementation, testing, maintenance and functional recovery) and economic data.

A module provides the collection and statistical analysis of climatic series, available since 1918. Based on these data, constantly updated by gauge data, other modules characterize the drought and assess the exceptionality of the extreme rainfall events that occurred or are expected.

Using the most appropriate statistical indexes, as the Standardized Precipitation Index (SPI), the drought module was equipped with a useful tool to identify dynamically the statistical trends of drought for different time durations, useful to characterize the drought form meteorological, hydrological and agricultural point of view. Estimate the probability distribution functions of extremes on the basis of a dual component approach (TCEV) at all levels of regionalization. Using time series of maximum rainfall from 1 hour to 5 days, it is now possible to assess the rain exceptionality or return period for each Gargano location on the basis of its elevation or to convert real-time short-term rainfall forecasts, drawn up by the national civil protection system, in return period for each location. These information can be very useful to support emergency management, whether due to rain triggering landslides and/or floods.

Another module was based on a geodatabase of catastrophic geo-hydrological events. Historical research of technical documentation through local and national newspapers, national and scientific publications database, was at the core of unpublished database of Gargano catastrophic geo-hydrological events, focusing on landslides and floods, which occurred since 1876. On this basis, the most critical areas were bounded and then thoroughly studied. In this way the location in which new gauges should be installed were selected.

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Hydro-geomorphological risk in the central and southern Marche: survey, analysis of river criticalities and proposals of intervention

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Keywords: Hydro-geomorphological risk, Human impact, Central Italy, Marche region.

Studies, scientific-technical knowledge and experience in the field of prevention and safety of degraded areas within river basins, evidenced that the river system is very sensitive and involves lot of factors; in this framework any evolutionary process, both natural or man-induced, can modify the hydro-geo-morphological setting with consequences that are evident, often after many years.

After a former analysis of the hydro-geomorphological and hydraulic risk associated with natural and man-made hazards carried out in the recent past along the main rivers of the central southern Marche, a joint collaboration with the Consorzio di Bonifica of the Marche region has been started, with the purpose of outlining the criticalities of the Marche fluvial network in the sector between the River Tenna to the south and the river Misa to the north, and to provide proper documentation about risk scenarios and remediation.

The study, taking into account the recent and disastrous hydrological events involving the Marche region and in particular the central areas, has been carried out taking into account the following key aspects.

Methodological aspect: the hydro-geomorphological studies are based on the identification of the morphological and hydraulic characteristics of the river beds able to determine and condition the natural flow regime. The fluvial dynamics is in fact strongly influenced by the slope of the river bed (and in general by the geomorphological characteristics of the reference catchment area) and by the “stream power” of the river itself. To characterize this aspect, census sheets of the natural criticalities and the hazard associated have been drafted.

Technical and design aspect: a lot of anthropic structures present along the rivers are critical elements mostly because they significantly reduced the flow regime along the river bed. This fact is related to past projects based on hydrological-hydraulic dynamics which is strongly changed in the recent years as a consequence of changes in the trend of precipitation; despite similar amounts of annual rainfall, it is appearing with a tropical behavior with violent and devastating rains concentrated in a very short time. To evidence this aspect another census sheet containing all relevant information required for the proper evaluation of the impact of the anthropic infrastructure along the river bed has been draft.

Ultimate goal: despite the difficulties of working in view of the overall recovery of the river bed, the study was developed with the intention of providing an applied research program that will have an implementation course after an appropriate involvement of public stakeholders.

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Geomorphological effect of The July '99 flash flood in the Tenna basin (central Italy)

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Keywords: Flash flood, Soil slip, landslides, Tenna river, Southern Marche.

In 1999 July the 9th, a severe rainfall event interested an area about 30 km2 in the middle portion of the Tenna river (central Marche), involving the territorial municipality located on the hydrographic left of the river. The mentioned hilly areas have a low relief energy, with flat summit, are strongly anthropized and characterized by the presence of arenaceous, pelitic-arenaceous and arenaceous-pelitic lithologies of Pliocene in age.

The flash flood event started at 2.30 pm, with the maximum about 4.00/5.00 pm, then continues, with minor intensity, until 10.30/11.00 pm. During two days (July 9 and 10) the total rainfall was of about 122mm, whereas in this area the month average is about 20mm. The event produced several gravitational phenomena and local flood events in correspondence of the secondary hydrographic network.

The recognized gravitational phenomena were essentially distinguished in fall and flow typologies. The former interested sub-vertical scarps on arenaceous-pelitic bedrock, without vegetation, with blocks of average diameter of 30 cm (in some cases the maximum dimension was up to 1 m3); the latter, flows and soil slip, interested mostly anthropic scarps, generally located at sides of roads. The flows phenomena evolved about 30 minutes after the maximum rain intensity; these phenomena occurred in colluvial deposits scarps and are related to the pores over pressure induced by the intense rainfall (high in short time). In correspondence the road systems we have a major problems: damages of the bridges noncorrectly dimensioned, removal of road places, overflows in correspondence of the minor drains, an increase of the water level about of 6 meters due to the solid transport induced by the rainfall event, in correspondence of the lateral natural channels.

Trough the 1825 cadastral map is possible to evidence that the hydrographic network are deeply modified, due to the intense anthropization of the area, creating a different government of the superficial water (biggest narrowing and/or rectification of the fluvial axis; obstruction of the stream due to the building of the anthropic structures and infrastructures without appropriate hydraulic criteria, etc.). The flash flood event allowed to establish that the phenomena previous described, and related damages, are associated to various causes: difficulties of discharge of the connection works between main and secondary hydrographic network; inadequate functional character and capacity of draining of the rain discharge network; unsuitability or complete absence of the remedial works on the fluvial river and secondary channel maintenance, intense presence of hydrogeological disorder and slope instability, emphasized by the progressive abandonment of the cultivation of the soil.

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150 years of shifts: channel mobility of the lower Scrivia river reach

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Keywords: Scrivia river, Channel migration, Channel changes, Channellization, Hystorical analysis, GIS GRASS.

Understanding the past river morphological changes is fundamental to carry out an effective and sustainable river and landscape management aiming to mitigate hydraulic and geomorphologic risks and to recover the fluvial environment. This work investigates the last 150 years of channel mobility of the lower Scrivia river (Piedmont, Italy), underlining the most important planimetric changes. The Scrivia river basin spereads over 1000 km^2; the main channel is about 90 km long, flowing northward from the Ligurian-Piedmontese Appennines, just North of Genova, to the Po river. The study reach (i.e. the last 15 km, from Castelnuovo Scrivia to the Po) represents the only part of the Scrivia river floodplain segment that shows clearly a single channel and a narrow, sinuous and deep-incised riverbed with very low slope. This research is based on a quantitative multitemporal analysis using GRASS GIS and QGIS software, supported by field surveys. Starting from six sets of georeferenced maps, aerial photos and orthophotos (1878, 1933, 1954, 1988, 2000 and 2012) the riverbed, considered as the portion of surface delimited by banks and sparsely covered by vegetation and with sand or gravel sediments, was manually digitized. Three sub-reaches were identified to perform a more detailed analysis. We assessed the channel mobility (for all years considered) and the channel width variations (only from 1954 to 2012) using a GIS procedure. Moreover, we outlined the historical channel shifting belt (Piégay et al., 2005; Clerici et al., 2015). The most significative shifts (some hundreds meters) both eastward and westward are noticed till 1954. The highest values are registered from 1878 to 1933 in the downstream sub-reach, where the Scrivia-Po confluence shifted northeastward with a kilometric migration. From 1954 to 1988 there were minor shifts largely related to meander cutoffs; hereafter the riverbed was quite stable. Concerning the channel width, it's possible to recognise a narrowing phase that culminates in 2000, succeded by a weak reversal trend. These results outline the last decades of channel mobility interrupted by bank protection structures. Nowadays a diffuse bank instability is registered; many lateral erosion processes have been activated, promoted by the collapse of lateral protection structures. These elements togheter with the formation of stable surfaces developed between the protected banks underline the vertical incision process that has accompanied the channel stabilization.

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Application of rainfall/runoff methods in mountain catchments: a case study from the southern Apennines

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Keywords: flood hazard mapping, ungauged catchments, gis-utilities.

This paper presents the first results of a study on analysis of flood hazard in ungauged mountain catchments that are associated with intensely urbanized alluvial fans. Some small, steep mountain catchments in the Maddalena Mts. ridge (southern Campania) have been chosen as test sites. In recent centuries, the selected basins have been repeatedly subject to heavy and intense precipitation events, which have caused flooding, with serious damages the correlated alluvial fan areas (Santangelo et al., 2006), or in the adjacent Vallo di Diano plain. The study is based on rainfall/runoff models. Historical rainfall data were collected by the Hydrological Annals (data until the 1990s), while data from year 2000 were made available by the Centro Funzionale per la previsione, prevenzione e monitoraggio rischi e l'allertamento ai fini di Protezione Civile della Regione Campania, that manages the national raingauges network. Rainfall data statistical processing allowed obtaining the depth–duration–frequency (DDF) curves, by which the amount of rain that is likely to occur at a given site for a specified duration and return period is estimated. Accessible spatial digitized information such as DEMs, land and soil use maps, geological/lithological maps and orthophotos, allowed delineating the drainage catchments and river network, to extract several morphological and hydrological parameters, to calculate and estimate some hydraulic parameters. The obtained data are used as input parameters to perform the hydrological/hydraulic simulations with HEC-HMS and HEC-RAS softwares that allow calculating the amount of rainfall, interception, infiltration, surface runoff, percolation, and determining the flow variables such as peak and date of peak discharge and total runoff volume. The simulation of the flood wave propagation along the hydraulic network that has been performed with this study may provide a first contribution to the assessment of hydraulic hazard for an area subject to repeated flooding phenomena.

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The impact of landslide dam on a Mediterranean small basin: the case of extinct Costantino lake (Calabria, Southern Italy)

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Keywords: Landslide dam, Landslide, Lake, Geomorphology, Italy.

Large landslides, triggered by earthquakes or heavy rainfall, often obstruct the river's path to form landslide dams. These phenomena can become very dangerous causing flooding both upstream, because of dam filling, and downstream, due to dam failure. In Italy, landslide dams are rather widespread along Alps and Apennines: although the identification of past events is a complex task, recently 300 landslide dams in a new open database were detected and collected (Tacconi Stefanelli et al., 2015).

The present work is focused on the landslide occurred on the Bonamico River basin giving life to the Costantino Lake, nowadays completely extinct. The basin is located in the Aspromonte mountain massif (Calabria, Southern Italy) covering an area of 136 km^2. The length of the main river channel is about 30 km with a mean gradient of 6% (Ergenzinger, 1992).

During the night of 3 to 4 January 1973 a large landslide occurred on the slopes of Mount Costantino, in the middle of the Buonamico's mountain valley. The volume was estimated to be approximately 10-16 million m^3. The mass movement caused river damming and creation of Costantino Lake. The event occurred in response to heavy rainfalls registered in 1972-1973 period, when several mass movements and widespread flooding in the regional area were counted. According to some local reports (Petrucci et al., 1996), the heavy precipitation events occurred in 1972-1973 can be considered as the exceptional weather phenomena within 1970-1980 decade, both for extreme values registered and for damages caused.

The Costantino Lake, arisen immediately after landslide failure, has reached 2,400 m in length on the river bed, with a perimeter of about 5,000 m and a maximum depth of 18 m. The total volume of the lake was estimated in 7,000,000 m^3. Since the river damming the water volume has steadily decreased, due to the load deposited by the river in the lake, which has raised the bottom. Due to further heavy rainfalls during 2008-2009, the Costantine Lake became extinct, 36 years after, on January 2009.

The purpose of the study is to increase the knowledge on the investigated site and update the data on the evolution of the entire phenomenon taking into account information gathered both through field visits and remote sensing techniques (aerial and satellite images).

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Flash flood hazard in Campania (Southern Apennines): the state of knowledge

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Keywords: Flash flood, alluvial fan, flooding hazard, Campania, Southern Apennines.

Along the Southern Apennines, drainage basins belonging to the category of small catchments, i.e. basins less than a few km^2 with a response time shorter than 1h, are a widespread geomorphic unit. These basins are characterised by high relief energy and low runoff rates, occurring mainly during autumn and spring. During rainfall events of high intensity and short duration, may be subject to flash floods. The delivery areas of these basins consist of piedmonts made up by coalescent alluvial fans hit by serious damage during the last decades. Cause to the relatively long time lags between floods and the consequent loss of historical memory, development of urban areas has increased. Studies aiming at defining flooding susceptibility are impelling in light of the projected climate change scenarios, suggesting an increase in the frequency of storms with rainfall patterns of high intensity within small space-time scales that are critical for the initiation of flash floods. In the last 10 years your research group faced the problem both at regional and at a local scale. Recognition of the most critical situations at a regional scale was based on morphometric analysis (Santangelo et al., 2012) allowing the evaluation of the susceptibility conditions among different basin/fan systems, by discriminating them in terms of the prevailing transport process (debris flow vs. water flood dominated). At local scale we focused our attention on extensively urbanized alluvial fans, trying to check different conditions of flooding susceptibility by means of GIS overlay of several thematic maps (Santangelo et al., 2011). The reconstruction of flooding scenarios at a very detailed scale (Lattari and Camposauro Mts) in some case has also involved the assessment of the magnitude of flash flood event (Marzano Mt.; Santo et al., 2015). We also collected a database of flash floods occurred in Southern Apennines from 1540 up to now, containing so far about 500 events, which is constantly updated. Then we selected several events from the catalogue in order to apply physical based model aiming at back-analysing the documented events, and simulating future similar scenarios in different triggering conditions.

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The Porchiano ephemeral lake: an example of temporary dams in pelitic bedrock in the Mount Ascensione area (southern Marche)

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Keywords: Ephemeral lake, Badlands, Ascensione Mountain.

The area of the Ascensione Mountain, represent the area in which the upper Pliocene bedfrock is located at the highest altitudes in Europe. The substrate consists of mudstones of the Plio-Pleistocene sedimentary cycle, infringing on the underlying Messinian turbidites of the Laga Formation where is interbedded a conglomerate body constituted by five events of marine sedimentation that represente the superposition, in sequence, of lithofacies conglomerate, arenaceous and arenaceous-pelitic levels.

Due to this geo-lithologiocal configuration, the whole area is characterized, in correspondence of franapoggio slopes, by different kind of landslides classified in flows and/or rotational slides; in correspondence of reggipoggio and/or traversopoggio slopes, is possible to recognize the typical badlands.

The meteorical events occurred during novembre-december 2013, that interested the Marche region, with concentrated rainfall principally in the southern area, they are triggered by numerous slopes of landslide phenomena, as well as flows of different entities within the gully landforms favored by the thixotropic behavior of the clay bedrock. One of these larger events, in particular, occurred on the slope in the left bank of the Torrente Chiaro Dead , to the south of Porchiano, about a week after the meteor event on 13 and 14 November 2013, giving rise to a dam that, in a short time, has generated a lake that is developed for a length of about 500 meters and a width varying up to a maximum of about 50 meters. The volume of reservoir is estimated about 70,000 cubic meters of water.

The landslide affects lithologies of Laga Formation (lithofacies pelitic-sandstone topped sequentially from mudstones to macrofossil and mudstones with silty-sandy horizons); analysis of aerial photos and cartographic documentation found, allowed to check, in addition to the characteristics of the movement, the dam and the volumes involved, such as the gravitational phenomenon was already in a state of pre-landslide for rain and the deepening of the drainage network caused the instability of the slope. On the upper part of the slope, in fact, is still visible the serie of escarpment, that the lower one is more recent whereas the higher represent tha landslide body in a ancient stage of evolution.

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Assessment of land cover changes on flood generation in a small Mediterranean catchment using an SCS-CN modeling approach: A case study in the Vernazza catchment, Cinque Terre National Park, Liguria, Italy

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Keywords: Flood, Mediterranean catchments, Curve Number, GIS.

Mediterranean catchments are sensitive to temperature oscillations, rainfall intensity and human activities; all of these factors imply significant environmental problems in terms of soil erosion and control of the meteoric waters.

The aim of this research is to assess the hydro- geomorphological effects of different land cover scenarios in the little Mediterranean Vernazza catchment in the Cinque Terre National Park, (Italy). It shows typical geomorphological features and characteristics present in most of the Ligurian coastal catchments. It has a small catchment area, very steep slopes and particular land-use pattern. The slopes have been almost completely terraced for vineyards and cultivation of olive groves during the past millennium. Due to socio-economic changes, the traditional cultivations on the terraced slopes have been progressively abandoned over the last decades. Subsequently, Mediterranean scrub and pine vegetation succession replaced the former cultivated areas.

The climate is Mediterranean, characterized by hot and dry summers and mild winters. In particular, on October, 25th 2011 a heavy rainfall affected the Cinque Terre area and especially the Vernazza catchment, with a cumulative daily rainfall of 539 mm recorded. This event triggered several slope movements and floods, causing 13 death casualties, as well as severe structural and economic damages.

To evaluate the hydrological and geomorphological consequences of different land cover, we applied a simple Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956) which was implemented in a GIS.

To validate the model we installed a multi-parametric measuring device within the river recording river runoff and sediment discharges.

To estimate the pedological conditions as input data for the SCS-CN model, the area was subdivided into Hydrological response Units (HRU). Soil samples, saturated hydraulic conductivity and soil infiltration were analyzed to estimate hydropedological characteristics of the single HRU.

To assess the SCS-CN model scenario, four different land use scenarios under the recent flood were simulated:1) The landscape under present conditions; 2) The re-cultivation of all abandoned terraces; 3) The landscape covered by garrigue and pine (recent abandoned terraces); 4) The landscape completely covered with Mediterranean scrub and woods (long time abandoned terraces).

Finally, we used runoff values of the SCS-CN method in a weighted flow accumulation procedure implemented in a GIS environment to calculate total discharges of the catchment.

This study evaluates, in addition to the climatic factors, the anthropogenic impact as an element of disturbance of the natural system. The applied methodology represent an valuable tool for the preparation of plans and strategies of land use /risk management in the Cinque Terre National Park.

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Fluvial Dynamics – the morphological-sedimentary approach

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Keywords: Fluvial Dynamics, riverbed - alluvial plain system, morphological-sedimentary approach.

Man has always had close and varied relations with the River: being the river at the same time a rich source of resources and dangers, on the one hand it promotes his welfare and development, and on the other hand it makes him exposed to risk and vulnerable. The complexity of the phenomena and the multiplicity of interests range in many fields of knowledge that use languages, criteria and different purposes, sometimes causing confusion in scientific setting of characters of fluvial processes and errors in the formulation and implementation of Laws and specific Technical Regulations.

The River is a structure that takes part in the hydrological cycle and the sedimentary cycle through flow discharges and sediment transport. The two cycles and the two phenomena are very different in duration and in the way. Sediment transport is a much more complex process than flow discharges and can not be correlated directly and simply with the same flow discharges and with the sediment supply from the hydrographic basin, but it binds to ones and the other through the concept of *sediment budget*.

The studies and the knowledge of a river can be varied according to the different fields and objectives of the same studies; however, there are two "base approaches" which, albeit to varying degrees, are always useful, if not necessary:

- **morphological-sedimentary approach**;
- **hydrologic-hydraulic approach**.

The two approaches do not arise as an alternative, they are placed in parallel and complement each other.

In the hydrologic-hydraulic approach, classic of Engineering Sciences, data and statistical methods are used and the Laws of Hydraulics are applied.

In the morphological-sedimentary approach, given the substantial absence of historical series of data on sediment transport, are considered, so to speak, its **"formative effects"** that are detectable in the "river system", observing it at different space-time scales:

- **Small scale**, at which the characters are considered at the **river basin** level, such as the drainage network or the climate and their variations in **geological time**;
- **Medium scale**, at which **homogeneous reaches** of the riverbed - floodplain system are considered, and their variations in **historical times**;
- **Large scale**, at which the various **components of the riverbed and floodplain** are considered and their variations during the individual events, in **real time**.

The knowledge obtained at different spatial-temporal scales used allows to define the actual behavior of the river, its variability, its trends and the reactions of the same river to the natural or induced input.

The morphological-sedimentary approach is expressed, as far as possible, with the quantitative language through parameters and models, defining the **"conceptual model"** of reference and, for each specific situation, the **"specific conceptual model"**.

SESSION S30

Groundwater resource among human needs, reuse and environmental requirements

CONVENERS AND CHAIRPERSONS

Alfonso Corniello (Università di Napoli Federico II)
Antonella Baiocchi (Università della Tuscia)
Emma Petrella (Università di Parma)
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Marco Tallini (Università de L'Aquila)

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Multivariate data analysis and numerical modeling: a combined approach to assess the Groundwater contamination in Milan Functional Urban Area

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Keywords: Multivariate statistical analysis, groundwater quality, multiple-point diffuse contamination.

The Italian law D.Lgs.152/2006 adopted the EU Water Framework Directive principles and entrusted the Regions with the task to identify the areas affected by groundwater diffuse pollution and to assess their contamination level. The proposed methodology (the Whole work has been supported by Regione Lombardia and ARPA Lombardia within the PLUMES Project) combines the numerical model approach, which defines the areas interested by a plume transit, with the statistical approach, in order to identify both point-source contamination (i.e. hot spots) and multiple point contamination that determine a status of diffuse contamination. The methodology was applied to the Functional Urban Area of Milan, where, at least since 40 years, chlorinated aliphatic hydrocarbons (TCE, PCE, TCM) have been the main groundwater contaminants in the unconfined and confined Aquifers and they have been constantly monitored by public authorities.

The study was divided into 2 different steps. In the former, the Cluster Analysis (CA, Vega et al., 1998; Otto, 1998) allowed to identify, for each contaminant, the hot spots that have been used as sources in the numerical transport model (MT3DMS, Zheng & Wang, 1999 and MODFLOW-2000, Harbaugh et al., 2000). The contaminant transport model, calibrated on the concentration values of 2014, gave important information about the influence of the plumes on the groundwater chemical status observed in the monitoring wells network. In the latter step, the monitoring wells located inside the plume areas were removed from the ARPA Lombardia contaminant concentration value dataset with the aim to keep just the concentrations representing the multiple-point diffuse contamination component. The new dataset was then used for the geostatistical analysis (Inverse Distance Weighted) in order to map the diffuse contamination, not directly influenced by hot spots. Lastly, the work defined reference values of diffuse contamination levels identified in the maps. To sum up, the results of the work provide a better understanding of the relationship between hotspot sources, multiple sources and diffuse pollution in the FUA.

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Reaction path modeling as a tool to investigate the water rock interaction in a crystalline aquifer in the Sila massif (Calabria)

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Keywords: Calabria, reaction path modeling, water geochemistry.

The aim of this work is to simulate the dissolution of granitic rocks, by means of the EQ3/6 software package, version 8.0, in order to investigating the weathering processes (Perri et al. 2014). The study has been carried out following three step: 1) water sampling and analyses; 2) rocks sampling and analyses; 3) geochemical modeling. The Sila Massif represents the major morphostructural high of the Ionian margin of north-eastern Calabria; it is made up of rock units involved in the Hercynian and Alpine orogens. The Sila Massif comprises a complete Paleozoic section named the Sila unit, consisting of three different Paleozoic metamorphic complexes: the low to very low-grade Bocchigliero complex, the greenschist to amphibolite facies of Mandatoriccio complex and the granulite-facies of Monte Gariglione complex, which is intruded by upper Paleozoic plutonic rocks of the Sila batholith. The batholith is characterized by several intrusions ranging in composition from granite and granodiorite to gabbro and leucomonzogranite. The Sila batholith is unconformably overlain by Mesozoic to Cenozoic sedimentary successions cropping out in the eastern and north-eastern flanks of the Sila Massif. Some groundwater parameters (pH, Eh, temperature, alkalinity and electrical conductivity) were measured in the field. The concentrations of Cl^-, Br^-, SO_4^{2-}, F^-, NO_3^-, and PO_4^{3-} were determined by HPLC, whereas Ca^{2+}, Mg^{2+}, Na^+, K^+, Si and some trace elements, were analysed by a quadrupole ICP-MS (Perkin Elmer/SCIEX) with collision reaction cell capable to reduce or avoid the formation of polyatomic spectral interferences. Data quality for major components was evaluated by charge balance. Precision and accuracy for minor and trace elements was evaluated against two different standard reference samples. Geochemical study (for methodology see Vespasiano et al. 2015) allows us to identify two main geochemical water types: a typical recharge water of Ca-HCO_3, type and a deeper Na- HCO_3 type (>700 m depth) with both high pH (near 10) and Fluorine concentration. The results of geochemical modeling show that the concentrations of Na, HCO_3 and pH value of water increase progressively owing to the dissolution of reactive minerals in flow paths. The concentration of Ca, Mg, K and SiO_2 first increase with the dissolution of reactant minerals, but later decrease when secondary minerals are precipitated and fluorite dissolves. Results of reaction path modeling reproduce satisfactorily the analytical concentrations of major elements in groundwater indicating the successful applicability of this modeling to investigating the weathering processes.

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Distribution of arsenic in rocks and groundwater of Cimino-Vico volcanic area: what can be inferred to identify water resources for human consumption

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Keywords: Arsenic, Volcanic aquifer, Water-rock interaction, Drinkable water, Italy.

The study focuses on the distribution of arsenic in groundwater of the Cimino-Vico volcanic area (central Italy), which is currently widely used for local drinking water supply and irrigation. This system shows a complex groundwater circulation, including a continuous basal aquifer, discontinuous perched aquifers, groundwater flows at high altitude, and local interactions with rising thermal fluids. Data on arsenic concentrations in 250 water samples from springs and wells, 101 samples from rock outcrops, and 3 rock samples from a core drilled in the thermal area of Viterbo, were taken into account and combined with already existing information.

Through an integrated approach, including leaching tests, and sequential extraction tests to investigate the arsenic behavior relatively to the water-rock interaction, and a geostatistical modeling of data, it has been possible to identify and tentatively quantify suitable groundwater resources with an arsenic concentration not exceeding 10 µg/L, the limit for drinking water for human consumption.

Results highlight that arsenic concentrations in groundwater are influenced by type of aquifer, groundwater flow path, arsenic content in the aquifer rocks, and interaction with fluids rising from depth. Waters circulating in the Vico volcanics have high concentrations of arsenic, both for basal and perched aquifers. In contrast, waters circulating in the Cimino volcanics present lower arsenic contents. Specifically, both waters of the basal aquifer in the NE sector of the system constituted by fissured rocks of the Cimino complex, and those flowing at high altitude in the lava domes of the same complex have arsenic contents lower than 10 µg/L.

Based on the results obtained in this study, the following recommendations have been defined in order to tap the groundwater resources hosted in volcanic aquifers, naturally contaminated with arsenic: i) the realization of wells close to hydrothermal areas should be avoided; ii) an excessive drawdown induced by pumping wells should be avoided; iii) the exploitation of aquifers characterized by short flow path should be preferred; iv) the more intensely fractured rocks of the Cimino volcano should be preferred, being characterized by low arsenic concentration and high transmissivity.

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Optimization of groundwater and surface water resources integrated management in protected areas: San Chiodo Spring, Sibillini Mounts, Central Italy

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Keywords: drinking water, National Parks, water resource integrated management, baseflow, recession curve.

Protection of water resources is a mandatory goal in National Park as the Sibillini Mountain one, located in Central Italy. Nevertheless, human requirements for drinking water supply are interested to tap groundwater from these areas, where the high value of environmental system is naturally safeguarding resources from pollution. At the same time, surface waters are interested also by withdrawals e.g. for renewable energy production by hydropower. The hydrogeological setting, where carbonate fractured and karstified aquifers host huge amount of groundwater resources, is favoring exploitation for different uses.

Consequently, an accurate evaluation of renewable water resources, of surface water/groundwater interactions, of baseflow discharge in drought periods, are necessary for developing a correct management, which must take into account environmental needs and human requests, in line with recent European Commission guidelines. To avoid arguments between the different actors interested in water resources management, namely in this case the Drinking Water company (SAN), the Sibillini Mountains National Park, the local municipalities, the River Basin Authority, and the Regional Authority of Marche Region, a monitoring of surface waters and groundwater has been performed in the 2014-2015 timeframe.

The research has been conducted on the upper basin of Nera river, located in the western area of central reliefs of Sibillini Mounts, Central Italy. The study, still ongoing, it aims to identify and characterize the water resources provided from regional aquifers and their baseflow, by using quantitative hydrogeology methods, supported by chemical and isotopic analyses and by recession curve analysis. An evaluation of possible impacts on the environment by a requested additional drinking water withdrawal has been conducted. About 150 L/s are nowadays tapped from San Chiodo spring and related tunneling drainage from SAN drinking company. In fact, most of the water resources drained by the tunnel are discharged in the Nera river, neighboring to the spring, to sustain the Minimum Environmental Flow. The Nera River shows an increase of more than 1000 L/s in discharge downstream of the San Chiodo spring, but with seasonal and yearly changes which in drought condition can lead to insufficient flow along the river, interested downstream by additional withdrawals. The upper Nera River basin results as the main discharge area of regional groundwater flowpath, draining the Basal, Maiolica and Scaglia calcarea aquifers, as confirmed by isotopic values.

By recession curve evaluation, it was possible to preview the minimum expected discharge along the Nera River downstream of the spring in different climatic conditions. An integrated management solution has been suggested, based on the discharge increase or decrease of the tunnel drainage system, ensuring both the requested drinking water amount and the minimum environmental flow into the Nera River.

Wastewater reuse: Weighing the pros &cons of soil and groundwater application

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Keywords: treated waste water reuse, groundwater impacts, irrigation.

In meeting water demand, many aquifers have been over-exploited by pumping in excess of recharge, leading to significant groundwater level decline and seawater intrusion in coastal areas. Water resources availability is going to be of the most important problems to face in the decades to come. To meet the growing water demand and also in response to water scarcity, measures to regulate demand and to increase supplies from new sources have been promoted. Among the policies to be cited, recycling and reuse of treated wastewater (TWW) is gaining popularity due to: the constantly improving quality of TWW discharges in line with increasing technology, and the need of non-conventional water sources in the context of integrated water resources management (IWRM) to meet the water demand. Over the last decade there has been significant growth in the application of reuse, important advances in reuse technologies, and an increase in the number of states that have implemented either rules or guidelines for reuse EPA,2012; BOE, 2007). The two water reuse options currently gaining prevalence, direct potable reuse (DPR, defined through an integrated planning process) and indirect potable reuse (IPR, are considered as part of the water cycle increasing water resources, improving the IWRM and supply security.

Agricultural irrigation and recreational facilities (ex. golf courses) and aquifer recharge (MAR) may be one the most well-known applications of reclaimed water. Successes, possible effects in groundwater and lessons learned are presented through specific case studies (De Bustamante et al., 2010; Candela et al; 2007; Candela et al., 2016; Teijón et al., 2016).

This manual is a revision of the "2004 Water Reuse Guidelines." This document is a summary of reuse guidelines, with supporting information, for thebenefit of utilities of utilities and regulatory agencies, particularly EPA.

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Geochemical study of the groundwater in the Sibari Plain (Calabria, Southern Italy)

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Keywords: Geochemical study, Sibari Plain, Marine intrusion.

The Sibari Plain, located in northeastern Calabria (southern Italy), represents a large coastal alluvial plain with considerable agricultural and tourist development. The plain is crossed by secondary ephemeral rivers and by the Crati River, the main regional river. The area is characterized by low rainfall and by the presence of a shallow unconfined and outcropping aquifer lying on a confined aquifer.

A geochemical survey was carried out on 103 selected wells from June to September 2012 in the framework of the project PON01_ 02818 AMICUS to investigate the chemical and isotopic composition of local groundwaters of the both aquifers. In situ measurements of electrical conductivity show a mean value of 1.1 mS/cm and a maximum value of 4.2 mS/cm close to Crati Delta area. The interpretation of chemical data allows one to recognize 4 hydrochemical facies. The Ca-HCO_3 hydrochemical facies (70 samples) has a Total Ionic Salinity (TIS) comprised between 6 and 34 meq/L. It is probably generated by calcite dissolution, a mineral phase that dissolves very quickly and that is very frequent in the study area. The Na-HCO_3 waters (13 samples) have TIS of 11 to 46 meq/L partly overlapping or somewhat higher than the TIS range of Ca-HCO_3 ones. The origin of these groundwaters is probably due to reflow of Ca-HCO_3 groundwater in shallow aquifers, previously flooded with seawater and/or brackish water (freshening). The Na-Cl hydrochemical facies e (14 samples) show a wide TIS range, from 22 to 80 meq/L, generally higher than that of Ca-HCO_3 water, but still below the TIS of 1210 meq/L of mean seawater. These waters are typically found in aquifers located near the coast and in the area of the Crati Delta. Close to the coastline, the origin of these waters can be related to ingression of seawater and/or brackish water within the sediments of the alluvial plain. This intrusion of seawater and/or brackish water takes place either directly (salt wedge), or through inflow of seawater along the riverbeds and subsequent infiltration into the surrounding shallow aquifers hosted in the alluvial deposits. This process may be favored by intense pumping from wells located near the riverbeds. The presence of Na-Cl waters in the inland area could be related to local upflow of deep brines (recorded in deep exploration boreholes) along tectonic discontinuities. The Ca-Cl type (3 samples) has TIS of 33-49 meq/L, exceeding that of the Ca-HCO_3 waters. This is a chemical composition generated by ionic exchange consequent to seawater ingression.

Furthermore, the average infiltration elevation for the groundwaters of the Sibari Plain was obtained by means of the $d^{18}O$ and d^2H values of H_2O. The computed average infiltration elevations, supported by the results of the numerical groundwater modelling, suggest that the Sibari Plain aquifers system receives underground inflows from the surrounding Pollino and Sila massifs.

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New considerations about nitrate content in groundwater of the alluvial-pyroclastic aquifer of the Campanian Plain (southern Italy)

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Keywords: groundwater, nitrate, diffuse contamination, isotopes, southern Italy.

The type of land use has an impact on groundwater quality. The application of manure, fertilizers and pesticides in agriculture is a primary source of groundwater pollution, especially diffuse pollution, that remains the most difficult to control. Nitrate in groundwater is the most common type of diffuse pollution.

Since the nineties, we registered in the alluvial-pyroclastic aquifer of the Campanian Plain very high nitrate contents (Corniello & Ducci, 2014) both in the shallow aquifer and in the deeper aquifer confined or semiconfined by a thick layer of tuff (Ignimbrite Campana, about 39Ky B.P). These high values were confirmed in the years 2000, up to 300 mg/L in the shallow aquifer and until 150 mg/L in the deeper aquifer. Isotopic studies carried out in a small sector of the area (Corniello & Ducci, 2009) revealed that here high contents of nitrate were prevalently due to the farming and the buffaloes breeding.

In these areas, groundwater suffers from different pressures, being intensive agriculture and buffalo-breeding the most important, in addition to illegal dumping and municipal waste. Moreover, in the coastal part near the Volturno mouth, a saltwater intrusion issue exists. Finally, these areas are affected by natural contamination and in different sectors high contents of fluoride, arsenic, sulphate, iron and manganese are present. Moreover, in the last decade the area degraded its reputation and has been called the “Land of Fire” by the media for the widespread illegal burning of waste. Consequently the appeal of local food products has been reduced and has thrown the agricultural economy (the area is the Campania Felix of the Roman times) of the region into crisis.

In the framework of a detailed study of the hydrogeology of the Campanian Plain, we have updated the knowledge about the nitrate contents in groundwater. In 2016 we started a hydrochemical monitoring of groundwater in wells, and in most of them we carried out isotopic analysis ($^{15}N/^{14}N$ and the $^{18}O/^{16}O$ ratios of dissolved nitrate) with the aim to define the sources of nitrate contamination.

Indeed, a wide range of measures can be implemented to limit pollution: control of the sewerage systems, land use restrictions, obligatory treatment of industrial waste waters, and prohibition of the use of certain chemicals. Although the partial adoption of these measures in the last years, nitrate content in groundwater of many areas of the Campanian Plain seems remain very high.

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The top of the intermediate confined acquifer map of S. E. Lamezia Plain (Calabria) as a support to the planning and the protection of water resources.

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Keywords: S. Eufemia Lamezia plain, confined acquifer, tectonics.

The area of study, which corresponds to the S. Eufemia Lamezia plain is characterized by a multi-layered aquifer, separated one from another by clayey horizons (Cuiuli, 2012; 2015). This plain lying in the Tyrrhenian sector of the "*Graben of Catanzaro*" that represent an important tectonic structure of the Calabrian-Peloritani Arc (Amodio Morelli et al., 1976). The Graben was created by sub-vertical faults with a prevailing direction WNW - ESE with a component left lateral strike-slipe (Gulla et al., 2005). In particular, this study aims to define the top of the intermediate confined aquifer map of S.E. Lamezia plain which, is little studied but strongly exploited because, respect to the shallow aquifer, is more productive and more protected by potential contamination due to the presence of the aquiclude/aquitard which isolates it by the top. The present work, conducted according stratigraphic analysis with the help of numerical interpolators, It has allowed mapping the top intermediate confined aquifer underlying the plain. The analysis of the stratigraphy shows that the studied aquifer is constituted by Pliocene deposits of sand and sandstones, confined to the top by Pliocene clay. The map produced and presented here, seems to confirm the structural-geological data of surface, showing also in depth the conditioning of tectonics on the study area and on the groundwater flow. The faults present have modeling the deposits of sands and sandstones, where is confined the studied aquifer. In particular the deepest sector of the aquifer is bordered by three fault lines that determine the greater depth than the context. Therefore, the present study aims to contribute to improving the knowledge of the hydrogeological scheme of S. Eufemia plain by returning the top intermediate confined aquifer map. The mapping produced, will find many applications in hydrogeological studies aimed at safeguarding and planning the use of the resource.

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Exceedance probability of some arsenic threshold values

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Keywords: Arsenic, DBVL, Indicator kriging, LNBLs.

The alluvial aquifers of the Po and Venetian Plain show high concentration of arsenic principally in reducing environments and it is often associated with the presence of organic matter. Our study concerns the Drainage Basin to the Venice Lagoon (DBVL) that is a densely populated area extending on the provinces of Venice, Padua and Treviso for approximately 2038 km^2. Notoriously the arsenic contamination of groundwater affects the DBVL. The UE's Groundwater Directive (GWD 2006/118/EC) suggests an arsenic Contamination Threshold Values (CTV) equal to 10 µg/l. In addition, the UE BRIDGE project proposes to use the 90^{th} percentile of the concentration data to estimate the Natural Background Level (NBL) (Müller et al., 2006). Nevertheless, this method provides only a statistical NBL value for the whole area without considering the spatial variation of the As concentration. Thus, the aim of this study is to improve the NBL concept using a geostatistical approach on a sensitive case where the NBL is seven times higher than the CTV. The dataset used in this work comes from the "A.Li.Na" project (founded by the Regional Environmental Agency) that aimed to define the NBLs of As, Fe, Mn and NH_4^+ into the DBVL's groundwater. Four seasonal surveys, from 2013 to 2014, collected the hydro-geochemical parameters in 50 piezometers. Primarily, we defined two thresholds that correspond respectively to the CTV and the median of the data over the CTV. These values were decided on the base of the dataset's statistical structure and the GWD 2006/118/EC. Subsequently, we evaluated the spatial distribution of the probability to exceed the defined thresholds using a geostatistical approach based on Indicator kriging. The results highlight different zones with high exceeding probability respect both the CTV and the median value. In particular, some portions of the study area have an exceeding probability ranging from 75% to 95% for both thresholds. Considering the geological setting of the DBVL, these high exceeding probability values correspond with the occurrence of both organic matter and reducing conditions. In conclusion, the spatial prediction of the exceeding probability could be useful to define the regions in which estimate the local NBLs, improving the procedure of NBL definition. In this way, the estimation of the NBL could be more realistic because it considers the spatial distribution of the studied chemical element/compound, distinguishing areas with a high natural concentration from polluted areas.

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Degradation of coastal aquifers of the Adriatic and Ionian Sea: the framework of knowledge

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Keywords: carbonate aquifer, seawater intrusion, geodatabase, Mediterranean Sea.

The progressive population growth in coastal areas and the increasing groundwater discharge, together with peculiarities of karst coastal aquifers constitute a huge worldwide problem, particularly relevant for coastal aquifers of the Mediterranean basin (Tulipano et al., 2005).

Karst aquifers in coastal regions are well known to be highly vulnerable to the overexploitation of groundwater resources, both from water increasing demand than from decreasing aquifer recharge due to climate changes. The coastal carbonate aquifers of the Mediterranean Sea, in particular the Adriatic and Ionian coast that extend between western Greece and Italy up to the eastern coast of Sicily not only ensure the socio-economic development of the populations but feeds with spring waters valuable wetland environments with negative effects on ecosystems (Barrocu, 2003; Bonacci, 2014; Eftimi & Zojer, 2015; Polemio, 2016).

The aim of this study is to develop management and forecast tools to identify the best way to assure enduring availability of high quality groundwater, and conciliate irrigation and drinking water demands. A geodatabase, collecting information for all carbonate aquifers present along the Adriatic and Ionian coast, will be first created. At the core there is a Geographic Information System, in which are placed the spatial information regarding the geology of aquifers, hydrogeological and geochemical features, together with climatic conditions and specific information concerning past, present and future groundwater usage.

The availability of tools that allow the integrated analysis of local hydrogeological situations, in reference to the wider areas where they are located, allows numerous applications. The system, in fact, is not only aimed to archiving, querying and mapping, but also to operate spatial analysis and the implementation of calculation systems, to return the hydrogeological conceptual models, supporting both the management of groundwater resources and the knowledge for the protection of coastal environments, and groundwater in general.

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Geological structural effects on groundwater flows: the case of the Riardo Plain (Southern Italy)

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Keywords: groundwater flows, multi-layered aquifer, Riardo Plain.

Coastal plains and internal-mountain areas are usually subjected to a high anthropogenic impact due to the land urbanization which can affect the quantity and quality of the groundwater resources. The Riardo Plain is an important Italian multi-layered alluvial aquifer that contributes to the feeds of important mineral springs used for the bottling of mineral water. In presence of "complex" aquifers the reconstruction of the hydrodynamic groundwater plays a key role in using and protecting the water resources. Simple models based on classification indices (vulnerability or indices of risk) are scarcely used although the data that we can use such as climatic data, topography and general physical properties of the soil (Gogu & Dassargues, 2000) are easily accessible. Moreover, a detailed knowledge of the hydrogeological conceptual model system is a prerequisite in order to arrive to a correct evaluation of the intrinsic vulnerability of the polluted aquifer (Beven, 2002; Dorte *et al*., 2008; Refsgaard *et al*. 2006). As recommended in the DRASTIC method's guidelines (Aller *et al.,*1987), the detailed reconstruction of the hydro-structural pattern of an area is essential in order to obtain information on the presence of hydro-dynamically differentiated water levels and the relationships among them. These aspects are key factors in the study area due to the presence of important industries that use the groundwater for the bottling of mineral water. Following the above consideration, this paper describes the hydrogeological structure of the internal-mountain Riardo Plain. It was defined the groundwater circulation characterized by two distinct aquifer levels separated by continuous banks of less permeable layers. From the study it was noticed that both the levels are linked with the carbonatic aquifer of the Mount Maggiore, which is located to the east and south of the plain. The study represents the base for a correct vulnerability assessment in an area of growing interest from the urban planning point of view.

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Balancing the Needs of Stakeholders and Ecosystems in the Management of the Nubian Aquifer, Northeast Africa

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Keywords: aquifer management, integrated ecosystem management, fossil aquifer, transboundary aquifer, Nubian Sandstone Aquifer.

The Nubian Sandstone Aquifer system, underlying Chad, Egypt, Libya, and Sudan, has a volume estimated to exceed 400,000 cubic kilometers and is one of the largest freshwater aquifers in the world. This aquifer has the potential to provide socio-economic transformation for nations at risk from food and water insecurity. Historically, development of the aquifer has been prevented by the high costs of constructing wells and distribution systems. Starting in the 1960s, Libya made significant investments in infrastructure to move this resource from remote desert locations to populated, coastal areas. As the other three countries consider options to take advantage of the aquifer, they must consider that the aquifer is only recharged during pluvial periods associated with glacial cycles and is therefore a finite fossil aquifer. This large but finite resource also supports fragile oasis ecosystems, which have been the very locations of economic exploitation. Several United Nations agencies and the Global Environment Facility have supported efforts to assure that ecosystem needs of the aquifer are balanced with the responsible transboundary management of the aquifer. These organizations have worked with the Nubian nations to develop a successful Strategic Action Programme which provides a roadmap for effective transboundary management of the aquifer. The Nubian nations are now in the initial stages of implementing this programme, in spite of recent political transformations and instability. This presentation will discuss the technical challenges to support the integrated management of the Nubian Sandstone Aquifer System.

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Management of groundwater at salinisation risk

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Keywords: Coastal aquifers, Seawater intrusion, Groundwater management.

Natural waters contain dissolved minerals from interactions with atmospheric and soil gases, mixing with other solutions, and/or interactions with the biosphere and lithosphere. In many cases, these processes result in natural waters containing solute or salinity above concentrations recommended for a specified use, which creates significant social and economic problems.

There are different measures, actions and practices for managing groundwater when the natural resource is exposed to salinization. Some of these measures have a mitigation objective. Other measures have a more adaptive approach and accept the high groundwater salinity but adjusting the groundwater use so that it is not harmful.

Moving from the lowest to the highest complexity, these approaches are the engineering approach, the discharge management approach, and the water and land management approach.

This research classifies the sources of groundwater salinization and defines in detail different management approaches to protecting the groundwater through salinization mitigation and/or groundwater salinity improvements. By focusing the attention on the effect of seawater intrusion, practical solutions are proposed.

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The hydrogeology of the Cassino basin from Boni to Celico: 30 years later

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Keywords: central Apennine, hydrogeological model, karst hydrostructure.

Cassino Plain is an intermontane basin located in the central Apennines (Saroli et al., 2014). Quaternary lacustrine and alluvial sequences fill the depression while limestone and dolostone, from Mesozoic to Cenozoic, constitute the main reliefs. Several limestone outcrops interrupt the flat morphology of the plain, as Trocchio and Porchio Mts. From a hydrogeological point of view, the Cassino basin hosts two important springs located on its edge: the Gari springs (elevation of 41-30 m a.s.l. and discharge of 13-18 m3/s) at NW and the Peccia Springs (elevation of 29-25 m a.s.l., discharge of 5 m3/s) at SE. In the studied area, the limestone and dolostone sequences reflect huge hydrostructures, with a high permeability for fracturing and karst. The remaining deposits with a minor permeability represent the aquiclude/aquitard of the system. Starting from the 1970's many conceptual models have been proposed to describe the geological and hydrogeological setting of the area, especially for the role of the Trocchio and Porchio Mts. and the possible communication between Gari and Peccia springs. The Boni model (Boni et al., 1986) considers Trocchio and Porchio Mts. as part of a horst and graben structure. According to this model, there would be continuity among the carbonatic blocks, from Gari to Peccia springs. The surrounding reliefs of the Cassino plain would be considered part of a single hydrostructure. It allows fixing the hydrogeological balance of the hydrostructure (the Simbruini-Ernici-Cairo Mts.) that feeds the Gari springs (Boni & Bono, 1973). Conversely, the Celico model (Celico, 1983 and references therein) considers Trocchio and Porchio Mts. as two carbonatic klippen overridden on less permeable deposits. The hydrostructure would be separated and a communication between Gari and Peccia springs would not be possible. A bibliographic research combined with new detailed geological and hydrogeological surveys, numerical simulations and an updated hydrogeological balance, brought in light new important data that support the independence between the Gari and Peccia springs. The revised hydrogeological model of the basin and its groundwater resources (a total water-discharge of 18-23 m3/s) are to be accurately considered for the optimization of the integrated management taking into account the human activities of the area (e.g. Aqueducts and Industrial plants) and the natural water-cycle.

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Analysis of rivers pollution in the Bagnara Calabra and Monasterace areas (Calabria – South Italy)

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Keywords: geochemical modeling, Southern Calabria, groundwater pollution.

In order to highlight possible pollution phenomena in the Bagnara Calabra and Monasterace areas (Calabria, southern Italy), twenty-two water samples from the main watershed (Sfalassà, Canalello, Gazziano, Allaro, Stilaro and Assi) were analyzed. This work was included within the Project PON01_02651 "SIGIEC" focused on the study of the reduction of pollutants and preservation in coastal environment in selected areas of Calabria.

Bagnara area is located along the western sector of the Aspromonte massif made up of gneiss (amphibolite facies), granites and pegmatitic intrusions. Basement is covered by sedimentary successions (Pleistocene-Holocene), arranged in several orders of terraces. Instead, Monasterace area is characterized by a crystalline basement, which consists of medium and low-grade metamorphites and granitoids (Stilo Unit), surmounted by sedimentary filling sequences of the ionian forearc basin (Stilo Capo d'Orlando formation, Argille Varicolori, Serravaliano-Tortoniano Succession and Messinian Succession).

Geochemical study allows us to identify four main geochemical water types: Na-Cl water for the samples Gaz3S and Sfa6, $Na\text{-}HCO_3$ for the samples Sfa1-2-3, Ass4 and Stil4, $NaSO_4$ water for the sample Sfa5S and $Ca\text{-}HCO_3$ water for the other samples.

Values of major and trace elements of fluvial waters have been compared with the Italian law limit values of D.lgs 152/2006, which establishes the lowest threshold of concentration for groundwater. In general, it was observed that all the samples do not show particular anomalies. Even NO_2 and NO_3, possible anthropogenic pollution indicators, stood at values below the lowest threshold.

From the above, the quality status of the examined areas, indicates acceptable values with no anomalies attributable to anthropogenic pollutants effects.

Data acquired on local rocks, and shallow groundwaters were used to reconstruct the irreversible rock-to-water mass exchanges occurring during the weathering of the granitoids and gneisses by means of the software package EQ3/6, version 8.0. The dissolution of granitoid is mainly governed by destruction of plagioclase and dolomite (which is present as monomineralic grains), whereas during the dissolution of gneisses, plagioclase and biotite give the main imprinting to the waters.

Results obtained from the geochemical modeling have been compared with analytical data and showed a good agreement which highlighted the reliability of the model outcomes.

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Relationship between water surplus and piezometric heads in the Upper Tiber aquifer (central Italy)

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Keywords: Water surplus, Piezometric head, Spectral analysis, Cross-correlation, Central Italy, Tiber River.

The present work shows the results of a hydrogeological study carried out on the alluvial aquifer of the Upper Tiber basin (131 km^2), characterized by no-flow boundary along the SW part and by constant head boundary in the NE part (alluvial fans). The analysis of groundwater levels of five piezometers, monitored by ARPA Umbria during 2001-2015 period, shows a different seasonal variability between the right and the left banks of the Tiber River. On the right bank, alluvial deposits with high permeability values outcrop, having a thickness of up to 100 m, which host an unconfined aquifer (Transmissivity, $T \approx 10^{-1}$ m^2/s): Pistrino, Piosina and Riosecco piezometers show a maximum groundwater monthly fluctuation of less than 3 m. On the left bank ($T \approx 10^{-2}$ m^2/s), groundwater monthly fluctuations for the Cerbara and San Giustino piezometers reach maximum values of 17 m and 8.7 m respectively. Rainfall and piezometric data series have been studied by means of spectral and cross spectrum techniques. Spectral analysis has been applied in determining the presence and statistical significance of climate cycles by processing data derived from rain gauges and the longest time series of piezometric heads (PH) of Pistrino and Riosecco piezometers. This analysis shows the presence of frequencies with high statistical significance (>99%), such as semiannual, annual, or others related to the warm phase of the ENSO (2.2 to 4.5 years). There are other cycles but with less statistical significance such as NAO or Sunspot. Frequencies below 0.5 years have been observed with high statistical significance. Some of these cycles detected in the piezometric series could be related to the Moon cycles (periodical expansions and compressions related to Earth tides).The cross spectrum analysis has been carried out by the Lomb-Scargle method to establish (at monthly scale) the relationship between rainfall and PH and as well as water surplus (WS) and PH.The analysis shows a delay between the rainfall signals and the response of PH which can range from 10 to 80 days. The delay between WS and PH of Pistrino and Riosecco is about 45 days. In conclusion, multiple regressions, performed over all piezometers, were used to estimate the monthly groundwater level (H_t) considering the groundwater level of the previous month (H_{t-1}), and WS up to the previous two months (WS_t; WS_{t-1}; WS_{t-2}). Good relationships were obtained with Coefficients of Determination (CoD) of about 0.90.Results obtained with multiple regressions agree with those obtained from cross spectrum analysis.

Session S31

Traditional and innovative approaches for hydrogeological surveys and monitoring

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Glenda Taddia (Politecnico di Torino)
Rosa Di Maio (Università di Napoli)

Piezometric level rise in the coastal alluvial plain of Naples (southern Italy) and its influence on civil engineering structures

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Keywords: Urban hydrogeology, groundwater level rise, pyroclastic-alluvial aquifer, underground structures.

In recent decades, the rise of piezometric levels has been observed in many urban and rural areas of the world, with severe economic and social impacts (Allocca et al., 2016). For the 95% of case studies reported in literature, a common cause was recognised as being related to a drastic decrease of groundwater exploitation, following a preceding period of overexploitation (Allocca et al., 2016).

Since the early 90's of the last century, in the coastal alluvial plain of Naples (southern Italy), the strong decrease of pumping for drinking water and industrial use has led to a progressive recovery of groundwater levels that are tending to natural original values (Corniello et al., 2003; Allocca & Celico, 2008).

The aim of this paper is to analyse the rising of piezometric levels and its hydrogeological interactions with buildings in the central sector of the coastal alluvial plain of Naples.

During the period October 2012-March 2015, the following methods and field investigations were carried out in the study area: i) implementation of a 2D hydrostratigraphic model of the multi-layered pyroclastic-alluvial aquifer through the analysis of lithostratigraphic data of 181 boreholes and the reconstruction of hydraulic conductivity logs; ii) slug tests and pumping tests; iii) multi-temporal hydrogeological monitoring of 149 wells, 9 piezometers and 36 river water levels and analysis of daily rainfall time series; iv) survey and monitoring of impacted buildings.

The results show that the rising of piezometric levels started in 1990 with a mean rate of about 0.30 m per year, even though characterized by a marked spatial heterogeneity. The maximum rise was identified in the north-western sector while the minimum in the middle/south-western sector, with values of about 2.05 m and 0.10 m respectively. Impacts on civil engineering structures were recorded since 2007, with a spatio-temporal variability related to the following hydrostratigraphic and anthropic factors: i) local confinement of groundwater due to surficial aquicludes; ii) depth and types of foundation structures; iii) loss of hydraulic efficiency of the surficial drainage system existing in the study area.

The obtained results represent the basis for a numerical groundwater flow modelling, which is a fundamental tool for designing measures to safeguard and mitigate this peculiar type of hydrogeological risk.

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Hydrogeological and vadose zone studies in the framework of the "Campania Trasparente" project (southern Italy)

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Keywords: Natural background levels, groundwater quality, aquifer vulnerability, vadose zone.

The "Campania Trasparente" project is a system-wide action aimed at improving the public awareness on the environmental state of the Campania region, by means of a health-environment correlation study. One of its primary tasks is to set-up new and synergistic efforts between researchers and public agencies, finalized to protect the region's agricultural and livestock resources as well as food consumers using a multidisciplinary approach. The project is based on the analysis of the agricultural and zootechnical productions and its effects on primary environmental matrices (soil, water, and air) and epidemiological features. Some researchers of the University of Naples Federico II are involved in this project with the specific task to assess groundwater quality and aquifer vulnerability, allowing also for possible interactions between the vadose zone and shallow aquifers (Romano, 2014).

The Campania region can be sketched in four principal hydrogeological frameworks (Allocca et al., 2007), with different groundwater quality and aquifer vulnerability: coastal and internal alluvial plains, with diffused anthropic pressures; Quaternary volcanic structures; Cenozoic flysch series, constituting hills in the interior part of the region and Mesozoic carbonate series, forming the main aquifers.

In the alluvial plains, nitrate, manganese and iron are the most common groundwater contaminants. High iron and manganese concentrations occur naturally, but high nitrate levels indicate severe contamination due to human activities (Corniello & Ducci, 2014). Hydrochemical characteristics of the volcanic show the presence of arsenic and fluoride of natural origin (Ducci & Sellerino, 2012). The hydrogeological studies are mainly focused on the characterization of the Natural Background Levels (NBLs) for significant ions in all the groundwater bodies of the region and on the assessment of aquifer vulnerability at different scales. By means of the operational support of the Istituto Zooprofilattico Sperimentale del Mezzogiorno (IZSM), extensive groundwater sampling and analyses (over 750 samples) in monitoring wells of farms will be carried out over the entire Campania region, and focused in those more vulnerable and potentially polluted locations.

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Ducci D. & Sellerino M. 2012. Natural background levels for some ions in groundwater of the Campania region (southern Italy). Environ. Earth Sci., 67, 683-693.

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Groundwater change and seismic activity: hydrogeological monitoring as a possible key to identification of seismic precursors

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Keywords: earthquakes hydrology, tidal analysis, earthquakes precursor, water level, stable isotopes.

Changes in groundwater levels related to earthquake have been investigated throughout the world, but most studies have focused on the effects of one large earthquake. The aim of this study was to identify potential patterns of level changes in response to several earthquakes, and possible variations of ion concentrations, gas compositions and isotopic ratios in groundwater. Doglioni et al. (2014) propose that in the tensional tectonic environment, the triangle of crust above the brittle ductile transition remains "suspended" while a dilated area forms during the interseismic period. Fluids may enter the fractured volume and water level decreases, when the triangle of crust above the brittle ductile transition starts to drop, the fracture confines and water level hence rises. This increase of water level culminates in the coseismic period. The Bussi sul Tirino area in Central Italy, a region with abundant groundwater resources has been selected. It is located near the active normal faults of the Sulmona basin, along the southeast-ward prolongation of the faults that nucleated the L'Aquila 2009 Mw 6.3 event. This area is characterized by low strain rate, an indicator of potential future larger earthquake. In the site, seismic and GPS stations exist. From July 2014 to March 2016 have been performed continuously monitoring of piezometric level, electrical conductivity and temperature on a groundwater well 100 m deep and discrete sampling of the main springs for chemical and isotopic analyses. The recorded data have been subsequently filtered to: i) separate the typical seasonal trends of the aquifer; ii) identify the piezometric variations due to intense rainfall events; iii) distinguish the tides, "solid" or "liquid", recognised using the frequency of recorded oscillations; iv) identify changes in water level due to river-aquifer relationship. After filtering, the data have been correlated with the seismic events recorded by the National Seismic Network in a distance range of about 40 km from the monitoring well. The correlations were performed only for the seismic events when rainfall lower than 2 mm/day was recorded, 2 days before and 2 days after the day of the seismic event. The preliminary comparison shows statistically supported correlation between groundwater changes and seismic activity. In particular, in several analysed time slots, seismic events are preceded by a slight, but significant decrease of the water table and followed or accompanied by a strong increase of the water table itself in the monitoring well. The results of chemical and isotopic analysis, repeated over time, highlight a stability characteristic of the regional groundwater flowpaths. The obtained first results are encouraging, in agreement with the theoretical previsions for areas characterized by extensional tectonics.

Doglioni C., Barba S., Carminati E. & Riguzzi F. 2014. Fault on-off versus coseismic fluids reaction. Geoscience Frontiers, doi: 10.1016/j.gsf.2013.08.004.

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Field test of a multi-frequency electromagnetic induction sensor for soil moisture monitoring in southern Italy test sites

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Keywords: Soil moisture, Electromagnetic induction, GEM300, Field survey, hillslope scale.

During last decades there has been a renewed interest in the use of geophysical methods for hydrological oriented studies. For a deeper comprehension of hydrological processes measurements and/or estimation of the spatial and temporal variations of the soil moisture are crucial. In this regard the electromagnetic induction method has appealing advantages, i.e. it does not require contact with the ground, it allows relatively fast surveys, it gives information related not only to the shallow soil and can be used in wooded areas. In this study, apparent electrical conductivity and soil moisture measurements were carried out by using a multi-frequency GEM-300 sensor and a MiniTrase TDR, respectively. The aim was to retrieve SM variations at the hillslope scale over four sites, characterized by different land-soil units, located in a small mountainous catchment in Southern Italy. Repeated measurements carried out over a fixed point showed that the signal variability of the GEM-300 sensor was negligible, other factors being constant. The results highlighted potential and limit of the multi-frequency EMI sensor to provide relatively rapid and sufficiently accurate estimate of soil moisture at the hillslope scale that are needed for hydrological and remote sensing applications.

Near surface geophysical techniques for the long-term monitoring of groundwater and subsoil contamination: first experimental results

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Keywords: Hydrocarbon contamination, Laboratory test, Cross-hole electrical resistivity tomographies.

Hydrocarbons contamination has become a serious environmental problem because of the increasing number of accidental spills caused by human activities and the important impact on ecosystems and shallow aquifers that infiltrated oil can produce when persists in the ground for a long time.

Therefore, we focus our attention to the long-term monitoring of hydrocarbon contaminated site applying near-surface geophysical techniques in order to characterize temporal and spatial distribution of the organic contaminants in vadose and saturated zone. In particular, electromagnetic techniques are proved to be very useful in mapping temporal and spatial distribution of the organic contaminants in the subsurface because electrical properties of the porous media are significantly influenced by hydrocarbons presence, and, after a certain period from the contamination, by possible contaminant and soil grain surface reactions and degrading bacterial activity development (Che-Alota et al., 2009; Atekwana & Atekwana, 2010).

In order to understand the geophysical response to long-term monitoring of spatial and temporal contaminants distributions changes in the subsoil, a controlled laboratory experiment was performed in the Hydrogeosite Laboratory of IMAA-CNR (Marsico Nuovo, Italy) by the injection of a LNAPL (diesel fuel) in a sand-box monitored by time-lapse electrical resistivity tomographies (ERTs). The box was filled with quartz-rich sand (81.17% silica, n = 0.35, and k = 5 x 10-3 m/s) and it was equipped with six boreholes and 36 stainless steel ring electrodes, at 5 cm spacing, for cross-hole electrical resistivity measurements. Two measurement phases were realized: first, we have characterized electrical resistivity of the uncontaminated soil; the second experimental phase has followed the diesel oil controlled spill in the sand-box vadose zone and consisted in the geophysical monitoring, for one year, of contaminant behaviour and its migration paths by cross-hole electrical resistivity measurements. In particular, in order to monitor the electrical behaviour, we have evaluated how the resistivity ratio has varied over time.

Experimental results allowed us to identify four different phases characterized by the alternation of conductive and resistive behaviours: a) electrical resistivity increased in the early period after the contamination, due to LNAPL presence, as expected; b) electrical resistivity recorded a sharp decrease after about eighteen days; c) electrical resistivity increased again from 40 to 90 days than it gradually decreased returning to pre-contamination values until about 160 days; d) electrical resistivity rapidly decreased until the end of the experiment.

In conclusion, even if our experimental results show a very complex electrical behaviour, the study underlines the capability of cross-hole electrical resistivity tomographies to realize a long-term non-invasive monitoring of subsoil contamination by LNAPL and that the relation between geophysical signal and contamination depends by time of investigation.

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Monitoring nitrate movement in soil columns by using 4D time-lapse ERT

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Keywords: Time-lapse ERT, wastewater reuse, nitrate movement.

The huge demand of suitable water for irrigation combined with water scarcity encourages the reuse of wastewater as an allowable water resource in agricultural practices. Due to their high organic (bacterial load) and inorganic (for example nitrates) concentration, the impact of wastewater, massively used for irrigation, is a crucial key point in agriculture (Casey et al., 2002). The knowledge of flow and transport processes and the soil-water interaction is an important item to evaluate the changes over the time of the soil texture and hence of the crop yield, caused by an intensive use of wastewater. These changes make unsustainable the agricultural practices. Non-invasive geophysical techniques represent an useful tool to better understand the water infiltration dynamics and the soil-water interaction.Among geophysical techniques, electrical methods are very sensitive to water content and water salinity and are widely used in agriculture to monitor the distribution of nitrate concentration (Gasperikova et al., 2012), the salt affecting soils (Haley et al., 2009), the water uptake by roots (Cassiani et al., 2016).In the studied case, a laboratory ERT survey has been carried out to evaluate the flow rate of nitrate in the soil, the interaction between soil and wastewater and to provide an estimation of nitrate concentration.ERT monitoring has been carried out on soil column, 40 cm high and 23 cm in diameter, by using 48 stainless steel nails as electrodes, placed along 4 vertical rows in order to simulate the cross boreholes arrangement and obtain a 3D imaging of the soil column.During the monitoring, the soil has been wetted several times with different flow rates; the used solution have electrical conductivity equal to 5.5 mS/cm and the solute concentration has been measured at the outflow.The infiltration dynamics have been monitored by means time-lapse ERT technique, repeating electrical measurements for about 1 month.ERT technique has been revealed an useful tool to track the movement of the highly conductive wastewater plume.

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Multidisciplinary approach and modeling of a case of complex contamination in an Adriatic coastal aquifer

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Keywords: Groundwater contamination, coastal aquifer, oil spill, metals mobilisation, reductive dechlorination.

The understanding and the identification of processes which influence mobility, transport and degradation of contaminants in groundwater are determining factors that have to be considered in polluted sites management, in order to correctly plan their remediation.

This research deals with a case of complex contamination in central Adriatic Italy. The studied site is a residential area located on a coastal aquifer which is made up by sandy and silty sandy deposits up to 15 meters thick, laying on a plio-pleistocenic clayey aquiclude (Desiderio & Rusi, 2003). Here, groundwater is heavily polluted by metals (i.e. Fe, Mn e As), hydrocarbons and chlorinated solvents (i.e. PCE, TCE, DCEs, VC), due to several distinct pollution sources.

As already known, the organic matter degradation, in this case related with an oil spill, triggers microbiological controlled redox processes in groundwater which involve redox-sensitive metallic species and chlorinated solvents (McCarty, 1997; Palmucci et al., 2016). In particular, the hydrocarbons degrades oxidising and acting as electron donors, while metallic species, as electron acceptors, are reduced and solubilised. Simultaneously, the chlorinated solvents degrades by mean of reductive dechlorination mechanism (i.e. from PCE to VC), acting as electron acceptors themselves. Nevertheless, since chlorinated solvents' reduction is not sometimes energetically favourable, heavily toxic by-products, as VC, can persist in groundwater. Thus, this dehalogenation process, when organic matter oxidises, competes with metallic species' reduction, complicating the dynamics which control the pollutants' diffusion in groundwater.

In order to forecast the pollution's evolution in the aquifer, considering the hydrogeological framework, the numerical modeling of transport and hydrogeochemical processes has been implemented (Appelo & Postma, 2005), as a refinement and validation of the initial conceptual model. The dataset used in this study has been collected in 9 groundwater sampling rounds in the 2009-2014 period, soil samplings at different depths, and 2 hydraulic head measurement rounds. The monitoring network is made up by 43 points.

The preliminary results confirm the metals' mobilisation linked with hydrocarbon pollution. This process seems to be more favoured than the reductive dechlorination, considering the very high concentrations of VC in the aquifer.

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McCarty P.L. 1997. Breathing with chlorinated solvents. Science, 276(5318), 1521-1522.
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Definition of shallow volcanic structures by integrating the Electrical Resistivity Tomography and the geological field observations: the Seiano tunnel and the Coroglio-Trentaremi cliff sites in the Campi Flegrei outer rim (Naples, Italy)

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Keywords: Volcanic structure, ERT, Geological observations, Campi Flegrei Caldera.

Geological survey on exposed sequences formed by volcanic rocks and pyroclastic deposits allow the reconstruction of the relationships among the different units and the definition of their geometry and lithological features. In the case of buried sequences, very frequent in calderas, the findings of such observations can be integrated with geophysical mapping in order to furnish a characterization of the buried structures through the reconstruction of the spatial distribution of the physical parameters that characterize the rocks. This is realized measuring some observable on the ground surface or along underground tunnels and caves. The collected dataset are subsequently inverted with a probabilistic approach, resulting in a model of the Earth interior, at a suitable scale, that justifies all the superficial observations. In particular, the volcanic environments are nowadays well known firstly thanks to the structural knowledge gained with geophysical exploration. In such a sense, the applied geophysics has a prominent role in the volcanological studies with significant results useful in the volcanic hazard evaluation and mitigation. In this framework, electrical and electromagnetic (EM) methods are among the most applied techniques, thanks to the large variability and great diagnostic power of the resistivity parameter in volcano-geothermal areas. The electrical methods, and in particular the Electrical Resistivity Tomography (ERT), are able to give useful findings despite the restrictions related to a reduced depths of investigation.

An example of such a capability is given, related to an application of the ERT imaging to the Campi Flegrei Caldera (CFc) area, one of the areas of highest volcanic hazard in the world. Our intents are to show how ERT imaging, integrated by geological observations, could contribute to furnish strong constrain about the inner structure of the buried volcanic deposits in order to define without ambiguity their characteristic, also thanks to the use of a controlled electrical source. To this aim, three ERT surveys are presented and discussed with geological data, as carried out in the context of the Posillipo hill (Seiano tunnel, Virgiliano Park and Coroglio-Trentaremi cliff), in the coastal area of the city of Naples. The CFc eastern rim has been reconstructed through this approach up to a few hundreds of meters depth. The findings have been geologically interpreted and compared with the available knowledge about the structure of the area. The application denotes how a good interaction between geophysical findings and geological field data makes ERT a tool suitably designed to define the volcanic edifices, despite the limits of the investigated depths.

Integrated monitoring technologies for the estimation of water content in unsaturated sandy soils

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Keywords: Water content, frequency domain reflectometry, infiltration, sandy soils.

The evaluation of water content of fine-grained unsaturated soils is important in the hydrogeological investigation because it play a key role in the recharge of aquifers, in the characterization and remediation of contaminated lands, etc. Depending on the observation scale and on the aim of investigation, different techniques may be used to evaluate the soil moisture in the laboratory and in the field. These include gravimetric direct measurement (θg) and volumetric indirect measurement (θv). It is generally known that there is a growing interest in the estimation of θv, so that much equipment for assessing this quantity in an indirect way have been developed. Although the indirect techniques are less expensive, and less time consuming than laboratory gravimetric direct measurements, results are deeply affected by the calibration of equipment. The present work has taken as reference the Frequency Domain Reflectometry (FDR) using a probe, PR2 Delta-T Device, that has been acquired thanks to the "*Ricerca di base 2014 Project – DIMBASE14*". The probe is constituted by six pairs of sensors, which allow the estimation of water content at different depths: 10, 20, 30, 40, 60 and 100 cm. In order to achieve reliable measures, the probe was calibrated at laboratory scale on two sandy soils widely outcropping in Central Italy: a limestone soil from "*Conca di Terni*" and a flyschoid sand from the Tiber River alluvial plane (Perugia). Several tests have been carried out at different dry density values belonging to the dry side of the Proctor curves. By using gravimetric water content and dry density obtained on laboratory samples, the volumetric water content was calculated and plotted vs. the permittivity measured by FDR probe. Results - coupled with calibration obtained by other Authors in the literature - allowed to obtain a general equation valid to estimate the water content on sandy soils of different composition and grain size distribution. After the calibration, the infiltration process was investigated through a five-layered soil column with 50 cm diameter and 110 cm height. We also show results discussed by checking changes of degree of saturation and the influence of entrapped air along the column.

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Management of shallow groundwater resources by data mining

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Keywords: shallow aquifer, data mining, management policy, time series.

Shallow groundwater may constitute an important water resources, if available. These are mainly used for irrigation, since easily reachable, however these practices, when uncontrolled, can cause overexploitation. In order to adopt adequate policies of management of these aquifers, it is necessary an accurate and comprehensive knowledge of the aquifer and of the dynamics of groundwater levels given rainfall supply. Due to their limited depth to groundwater, these aquifers are often monitored, and long time series are available. The analysis of the responses of aquifers to the variations of rain precipitations, or to changes in pumping activities, is a strategic support to the implementation of policies of water management. The availability of time series of data allows for the use of data mining approach, i.e. those numerical approaches, which extract unknown patterns and scientific knowledge from measured data (Doglioni and Simeone, 2015b) . Starting from the measured piezometric levels of water tables and the correspondent time series of rainfall values, data mining techniques can identify models, representative of the responses of water table levels to precipitations.

Here, a well-established data mining technique, EPRMOGA, used both for porous and karst aquifers (Doglioni et al., 2010; 2015a; Doglioni and Simeone, 2014) is used in order to model average monthly water table fluctuations in terms of responses to total monthly precipitations. In particular, three shallow porous aquifers are modelled, located in three different areas of Italy. These are: the aquifer of Brindisi plain, in south east of Italy, the aquifer of Metaponto, in south Italy and the upper aquifer of the Po plain, in the area of Pavia, north Italy. It is shown how EPRMOGA is able to identify models as explicit intelligible equations, where water table level is the output and precipitations and past measured values of water levels are the inputs. Finally, it is shown how the variations of boundary conditions can affect the results, in terms of fitness of model to measured data.

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GNSS contribution to monitor severe rainfalls

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Keywords: GNSS meteorology, Atmosphere monitoring, Precipitable Water Vapour, Early-warning systems.

There are different techniques, models and measures of atmospheric parameters used in weather forecasting: from surface observations on the ground to weather balloons, from meteorological radar to satellite images. A useful contribution to atmosphere monitoring may be provided by the analysis of GNSS (Global Navigation Satellite System) signals. In fact, the analysis of GNSS delays on one hand allows to improve GNSS positioning, and, on the other hand, to observe and measure the atmospheric water vapour. A good estimation of water vapour amount in atmosphere is important in deepening the knowledge of severe meteorological events, for both a posteriori and near real-time applications.

GNSS observations can be performed under every meteorological condition, this leading to the possibility of continuous atmosphere monitoring with reliable results, even during severe events.

By means of local estimations of Zenith Total Delay (ZTD) for a GNSS Permanent Stations (PSs) network, integrated with Pressure (P) and Temperature (T) measurements and a Digital Terrain Model (DTM), the authors have identified a procedure to monitor the Precipitable Water Vapour (PWV) content and its evolution in time (ΔPWV) on regional extended and orographically complex area.

The procedure is carried out in GIS environment using GRASS software. The first case studies covered approximately the north-western part of Italy, using data coming from existing infrastructures such as international, national and regional PSs networks, processed through common elaboration techniques, P and T data from NOAA (National Oceanic and Atmospheric Administration) and the ASTER GDEM (Global Digital Elevation Model).

PWV maps result extremely useful, giving important indications about the maximum potential precipitation level. Additionally, the ΔPWV pattern could be associated with the initiation of severe rainfall, giving further helpful information for forecasts and early-warning systems.

Since the analysis of GNSS data is independent from weather models, the procedure results could be useful as starting conditions for existing Numerical Weather Prediction (NWP) models or as comparison with them, to better understand the meteorological phenomena.

Monitoring of organic load reduction in olive-mill wastewater by biochar using the spectral induced polarization (SIP) method

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Keywords: spectral induced polarization, biochar, bioremediation, olive-mill wastewater.

Olive oil production process creates a large volume of organic waste rich in phenols and other substances hazardous for human health and the environment. The olive-mill wastewater (OMW) is usually disposed of into unprotected and uncontrolled evaporation ponds nearby the main olive oil production facility. OMW disposal often leads to soil and groundwater degradation and is a direct threat to the flora and fauna of the area. A holistic strategic approach for the management of OMW is required. One promising method for organic load removal is the use of biochar. Lately, rice husk and corncob biochar have shown high sorption capacity towards phenolic compounds (Mohan et al., 2014). Essential to the success of any organic load removal approach is the accurate monitoring of the process. The spectral induced polarization (SIP) method is a prime candidate for a monitoring tool in OWM remediation processes using biochar. Previous work has established the sensitivity of induced polarization on OMW (Ntarlagiannis et al., 2016); as part of this work we established the dependence of electrical parameters on OMW concentration in porous media. Furthermore, the links between SIP and a variety of biochar materials have been established (Haegel et al., 2013). With this work we present early results on the use of spectral induced polarization (SIP) method as a monitoring aid in a controlled laboratory experiment with biochar used as a tool for countering land degradation (Barrow, 2012).

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Permeability evaluation of fractured rock-masses in the Cassino area (central Italy)

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Keywords: geo-mechanical analysis, karst, numerical simulation, permeability, rock-mass.

The study combines geo-mechanical data and numerical simulations, in order to estimate the permeability of rock-masses in the Cassino area, characterized by a thick sequence of limestone and dolostone (Saroli et al., 2014). During the surveys, the geo-mechanical measures revealed the rock-masses by several joint-sets with a homogeneous orientation (dip and dip-slip). The measures provided a mean value of the spacing and the opening for every single joint-set, while the roughness was not considered. Average geo-mechanical data allowed constructing twelve rock-cubes with a different set of spacing and aperture having a volume of 1m3. In order to obtain different permeability values, the Authors investigated the reconstructed cubes by numerical simulations, using a FEM analysis with the software COMSOL MULTIPHYSICS®. Every cube is oriented according with the following notation: East=positive x; North=positive y; Up=positive z. The Authors considered simply valid the cubic-law for every discontinuity (Surette et al., 2008; Klimezak et al., 2010) and a regional hydraulic gradient of the 0,5 %. Numerical simulations have given back a wide range of permeability values, typical of fractured rock-masses. The obtained permeability values strongly increase with the opening extent, according with the cubic-law. Permeability changes with reduction of the spacing has been recorded too. The permeability covers a high range of values but it is almost isotrope for each spacing/aperture set. Indeed, just minor variations have been recorded among the permeability directions. The Kzz (permeability component along the z-axis) is slightly higher than the Kxx and Kyy (respectively, permeability along the x-axis and y-axis), for every cube. At the end, the comparison with direct values from pumping test (Celico, 1983) suggests clues about the representativeness of the obtained data and the limit of the application of the cubic law in the studied area. Combining a traditional (pumping tests) and a new approach (numerical simulation from geomechanical data), the study deepens the behavior of the permeability values of rock-masses, at different study-scales.

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High-resolution seismic imaging of complex environments for groundwater research. The example of Val di Cecina area (Tuscany, Italy)

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Keywords: Seismic surveys, Neogenic deposits, Groundwater resources, Central Tuscany.

This research project intends to improve the knowledge of potentially water-bearing area near the town of Bibbona (LI), falling in the eastern portion of the groundwater body of the Val di Cecina area, coastal plain and the surrounding hills, and propose a sustainably of groundwater resources for drinking water in these areas.

The study area, as well as the entire south-western Tuscany, is characterized by a pre-Neogene substrate, consisting of Ligurian Units, Subligurian Units and Tuscan Nappe, topped unconformably by a terrigenous cover organized in more sedimentary cycles that extend from the Upper Tortonian to Pleistocene.

Using a single IVI-Minivib® high-frequency vibratory source, we acquired and processed about 1400 meters long high-resolution seismic reflection/refraction profiles, along a representative section of the geological units above mentioned. A preliminary analysis of the outcrops suggested the presence of very dipping reflectors and the high heterogeneity of deposits (i.e. miocenic conglomerates). These factors, together with the presence of several tectonics contacts, often hinder the seismic imaging. In order to overcome most of the factors limiting the data quality in those environments, data were recorded by Dense-wide-aperture (DWA) arrays (Bruno et al., 2013) made of 192 vertical geophones with a 4.5 Hz eigen-frequency placed at 5 m intervals. Moreover, DWA geometry allowed a meaningful interaction between refraction and reflection data processing.

Seismic refraction analysis was performed through a SIRT algorithm (Gilbert, 1972) to obtain tomographic model of Vp velocity. After a pre-processing flow, aimed at improving signal resolution and signal/noise ratio, DMO technique was also applied for imaging steep dip events. Seismic section was migrated in depth, using the interval velocity model obtained from the conversion of the final RMS velocity macromodel.

The tomographic model and seismic profile acquired in the studied area, show a general monoclinalic trim, plunging to the west, of the miocenic formations (turolian conglomerates and messinian marine deposits) which will deepen rapidly below the Pliocene clays (Argille Azzurre Fm.) also reaching depths greater than 300 m. Therefore, it is argued that the potentially water-bearing area (turolian conglomerates) is to be found, in the investigated area, to the under Pliocene deposits at great depths or in the hills located to the East of the city of Bibbona. Aquifers of modest dimensions were identified in Quaternary alluvial deposits.

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Chlorinated solvents contaminated site characterization by the use of advanced techniques: multilevel sampling, CSIA, BMTs and numerical modeling

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Keywords: Chlorinated solvents; Compound-Specific Isotope Analysis (CSIA); Biological Molecular Tools (BMTs

Background: Chlorinated solvents contaminated sites entail costly management costs and often create significant impacts to the environment. Innovative tools such Compound-Specific Isotope Analysis (CSIA), Molecular Biological Tools (MBTs) and fate and transport models and detailed multilevel nested wells sampling (MNWs) can provide unequivocal information for site characterization and assessment of natural attenuation processes, particularly biodegradation.

Objectives: This contribution explores the potential for the tri-element CSIA approach, MBTs, transport models and MNWs to study a heavy monochlobenzene (MCB) and benzene contamination at a mega-site where potential multiple sources are presents.

Results: A significant difference in the $d^{13}C/d^{2}H$, $d^{13}C/d^{37}Cl$, $/d^{37}Cl/d^{2}H$ and $d^{13}C/d^{37}Cl/d^{2}H$ for MCB and $d^{13}C/d^{2}H$ for benzene - in the high concentration spots - allowed distinguishing two distinct sources and plumes (merged at some areas). By the use of MNWs a detailed vertical distribution of the contaminants thought the aquifer was assessed.

Concerning natural attenuation processes, although the site is characterized by reducing conditions with high concentrations of $CH_{4,}$ MBTs results indicated the presence of mainly aerobic potential degraders within the indigenous community at the site and ruled out a significant presence of dehalococcoides or dehalobacters. Microcosms experiments and soil slurry with in-situ cultures showed a unique $d^{13}C/d^{2}H$, $d^{13}C/d^{37}Cl$, $/d^{37}Cl/d^{2}H$ and $d^{13}C/d^{37}Cl/d^{2}H$ trend with almost no enrichment for ^{13}C and $d^{2}H$ but a ^{37}Cl Ɛ of – 0.7 ‰.

The tri $d^{13}C/d^{37}Cl/d^{2}H$ data also seem to indicate aerobic biodegradation processes as the main natural attenuation mechanism. Finally, regarding benzene, the $d^{13}C/d^{2}H$ data showed that benzene present at the site is probably not linked to MCB dehalogenation processes but is rather a primary contaminant; these data also showed benzene is being attenuated by biodegradation. Since not varying as a consequence of biodegradation processes, $d^{13}C$ and $d^{2}H$ for MCB were used in combination with the transport models to estimate the contribution to the contamination from the two distinct sources. After estimating the mixing ratios among the plumes, $d^{37}Cl$ was successfully used as a tracer to assess the natural attenuation processes at the site.

These results demonstrated the potential of combining tri-element CSIA in combination with other tools, particularly important insights regarding MCB natural attenuation were obtained by applying tri $d^{13}C$, $d^{37}Cl$, and $d^{2}H$ CSIA analyses.

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Airborne EM mapping over large areas for the hydrogeological study of the Peace River Basin, British Columbia, Canada. Preliminary results

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Keywords: AEM Hydrogeophysics Glacial aquifers Hydrogeological modeling.

We show the preliminary results of a regional hydrogeophysical study in the Peace River area in British Columbia, Canada. The objectives of the Peace Project are to map shallow aquifers through the integration of shallow well data, shallow 3D seismic and airborne EM (AEM). The project area covers approximately a 8,000 square kilometer area. A SkyTEM survey of approximately 21000 line-km was flown during the summer of 2015 and is undergoing advanced processing and inversions to provide the basis for subsequent hydrogeological modelling. The initial main target from a hydrogeological point of view was the Quaternary glacial aquifers. The Quaternary comprises unconsolidated deposits, typically 15m in thickness (including glaciofluvial, glaciolacustrine deposits, tills, colluvial and fluvial units. The underlying bedrock comprises Cretaceous-aged shales and sandstones, namely, the Dunvegan (sandstones and conglomerates), Sully (shales and siltstones), Sikanni (sandstones) and Buckinghorse (shales) formations. Airborne Electromagnetics plays a significant role to build the hydrogeological moel. Mapping groundwater with AEM is not a “bump” anomaly exercise. It requires a dedicated, specialized workflow, from data processing to inversions and data integration. The processed data were inverted with spatially constrained (SCI, Viezzoli et al., 2008) multilayered inversion. Borehole data, from oil and gas wells primarily, is used to groundtruth the airborne geophysical data, thus providing critical information to assist the interpretation of the geophysical model into a geological-hydrogeological perspective. The first results presented show some resistive features that are in fair spatial agreement with outlines of paleovalleys and thick Quaternary aquifers inferred from the borehole data (reinterpreted gamma logs), while others do not appear to correlate. It should be noted that borehole density and quality in the area is variable. In general, the inverted resistivity models recover with good accuracy depth to bedrock, both shallow and deep. Some formations (e.g., Sully) show consistent resistivity responses, while others vary (e.g., Sikanni and Dunvegan). This can be due to either water quality variations, local inhomogeneities in the rock matrix or both. The Quaternary units also display a degree of vertical variations in resistivity, probably due to the presence of glaciolacustrine deposits. AEM has been shown to be a very effective methodology for efficiently mapping large regional areas. The results presented correlate well with known geology, both near surface or at intermediate depths. They also provide preliminary insight into the wealth of additional hydrogeological information which will be possible from the dataset, when properly integrated and interpreted.

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Viezzoli A., Christiansen A.V., Auken E., Soerensen K.I. 2008. Quasi-3D modelling of airborne TEM data by spatially constrained inversion. Geophysics, 73, F105-F113.

The role of fault damage zones in fluid flow: the case study of the Euganean Geothermal System (NE Italy)

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Keywords: fault damage zone, numerical modelling, thermal water.

The Euganean Geothermal Field (EGF) extends on a plain band to the south of Padova in the central part of Veneto Region (NE Italy). Approximately 400 wells up to 1 km deep have been drilled since 1950s, and 170 wells are currently active exploiting $14*10^6$ m^3/y of thermal water. The water has a temperature from 65°C to 86°C, and it is used for balneotherapy feeding 240 pools. Therefore, the EGF represents an important thermal field of Italy, and its recreational tourism is a significant economic resource for the Veneto region. The EGF is the outflow area of a regional hydrothermal system (Pola et al., 2015). The water is of meteoric origin infiltrating 100 km to the north of the EGF in the Veneto Prealps. The water flows towards the South in a Mesozoic carbonate aquifer reaching a depth of 3 km and warming to 100°C due to a normal geothermal gradient. The flow is enhanced by the highly permeable damage zone of the regional Schio-Vicenza fault systems (SVFS). In the EGF area, the water intercepts a local network of fractures associated to an interaction zone between the SVFS. The water rises quickly through the open fractures, and subsequently it spreads horizontally within fractured layers located at depth from 300 m to 1 km. The aim of this research is to understand the role of SVFS on the regional fluid flow, as well as the influence of the local fractures mesh on the upwelling of the hot water. The FEFLOW code is employed to reproduce the conceptual model of the thermal system in a 3D numerical model using the Equivalent Porous Medium Approach. The regional geological setting is simplified by 3 planar hydrostratigraphic units with a thickness from 1.4 km to 2 km. The units are simulated using 26 layers of constant thickness, and the values of their hydro-thermal properties are estimated using literature values. In addition, the damage zones of the faults are modelled increasing the local permeability by 1 order of magnitude compared with the protolith, while the permeability in the central part of the domain is increased by 2 order of magnitude representing the fracture mesh. Preliminary results show the development of convective cells along the damage zones and the increase of the temperature in the EGF subsurface. However, the modelled temperature is lower than that estimated into the reservoir. Therefore, a sensitivity analysis will be performed to evaluate the impact of the permeability (i.e., permeability of the units, ratios between the permeability of the protolith and the fractured rock and between horizontal and vertical permeability) on the modelled temperature in the EGF. This impact will be evaluated comparing the results with the subsurface temperature measured with thermal logs in the wells.

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Time evolution of self-potential anomaly sources due to organic contaminant transport by different data inversion approaches

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Keywords: olive oil mills wastes, contamination, self-potential surveys, inversion methods.

The infiltration of organic contaminants in the subsoil may cause major effect on groundwater quality. The employ of real-time monitoring of physical and/or chemical parameters as well as of simulation modelling has proved an useful tool for predicting the underground solute transport (Cassiani & Binley, 2005). Among the commonly used geophysical methods in hydrology, the electrical methods have proved the most effective techniques for detecting soil and/or groundwater pollution due to changes in soil electrical properties resulting from biodegradation processes (Ntarlagiannis et al., 2016 and references therein). In particular, this work is focused on modelling of the transport of olive oil mill wastes (OOMWs) by using different inversion approaches of self-potential (SP) data acquired at different times in a pilot study area (i.e. an evaporation pond of OOMWs) located in western Crete (Greece). Specifically, five SP datasets acquired from May to July 2014 along a profile located about 15 m from Keritis river have been analyzed. Quantitative interpretations of selected SP anomaly sources, likely related to zones with contamination from OOMWs, are attempted by using simple polarized source models whose parameters have to be determined. In particular, three different methods based on high-resolution spectral analysis, tomographic approach and global optimization, respectively, have been used to estimate the time evolution of the source depth. A validation of the obtained results has been provided by comparison with the electrical resistivity distributions coming from time-lapse resistivity tomography surveys performed along the SP measurement profile.

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Integration of remotely sensed data for the estimation of groundwater recharge in karst aquifers of southern Italy

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Keywords: Karst aquifers, actual evapotranspiration, remote sensing data, southern Italy.

Karst aquifers represent important groundwater resources in the world. In southern Italy, they are the main source of drinking water and play a crucial role for socio-economic development of the territory and hydro-bio-geomorphological conservation of groundwater-dependent ecosystems (Allocca et al., 2015).

The reliable estimation and modelling of groundwater recharge of these aquifers is a fundamental tool for the management of water resources at a regional scale, also considering environmental issues of river ecosystems and the effects of climate changes. Due to mountainous morphology of karst aquifers and the associated sparseness of rain and air temperature gauges, the assessment of hydrological parameters needed for the estimation of groundwater recharge is a challenging issue to be faced. In such a framework an integration of terrestrial and remotely sensed data is a promising approach to limit uncertainties. In particular, the estimation of actual evapotranspiration (Eta) is very difficult at the regional scale, especially in karst areas of the southern Italy which are characterized by variable conditions of land use and vegetation coverage.

In this research, we report preliminary results of a study aimed to estimate ETa in karst aquifers of a wide area of southern Italy, extended over about 30.000 km^2, by using remotely sensed data derived by the MODIS satellite. In a GIS environment, hydrogeological, hydropedological, geomorfological and land use data of the karst aquifers (Allocca et al., 2014), were implemented along with the time series of annual ETa, as estimated by the MODIS Global Evapotranspiration Project for the period 2000-2014 by an advanced algorithm (Mu et al., 2011) based on the Penman-Monteith equation (Monteith, 1965). Time series of annual rainfall and mean annual air temperature recorded by meteorological networks in the same period (150 temperature stations, 266 rain stations) were also implemented in the GIS environment, in order to realize hydrological distributed models.

Results show a strong spatial variability of ETa, at different temporal scale, that characterizes all karst aquifers. In addition, significant relationships between ETa and air temperature, rainfall, land use and vegetation coverage were found.

Allocca V., Manna F., De Vita P. & Nimmo J.R. 2015. Groundwater recharge assessment at local and episodic scale in a soil mantled perched karst aquifer in southern Italy. Journal of Hydrology, 529, 843-853.

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Multiscale integrated approach to understand the structure and evolution of the Neapolitan Yellow Tuff (NYT) caldera off the Campi Flegrei, eastern Tyrrhenian margin

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Keywords: Campi Flegrei, resurgent caldera, high-resolution reflection seismics, Pozzuoli Bay, eastern Tyrrhenian margin.

Resurgent calderas are among the largest and most dynamic volcanic structures on earth. They are typically associated with major eruptions with considerable volumes of pyroclastic deposits accompanied by large collapse structures and late stage deformation and uplift of the intra-caldera floor region. The Campi Flegrei is a vast volcanic area located on the coastal zone of the Campania region of SW Italy, a large part of which develops off the Naples (Pozzuoli) Bay. The area has been active since at least ~80 ka BP and is structurally dominated by a caldera collapse, ca. 8 km in diameter, associated with the eruption of the Neapolitan Yellow Tuff (NYT), a 30–50 km3 Dense Rock Equivalent ignimbrite dated at ca. 15 ka BP. In the past decades the shallow crustal structure of the NYT caldera has been mostly reconstructed using gravimetric and magnetic data, seismic tomography images and modelling (analogue) experiments, whereas, the structural elements of the caldera collapse in the Pozzuoli Bay have been largely inferred, based on seafloor morphology and associated deposits. Despite the conspicuous research so far conducted off the Campi Flegrei, the stratigraphic architecture of the NYT caldera structure and inner caldera deposits is still poorly understood. This is mostly because of the intrinsic limitations due to the insufficient resolution of previous seismic datasets, as well as to the lack of reliable geologic calibration of the offshore geophysical data.

In this study we present a detailed structural and stratigraphic reconstruction of the submerged part of the NYT caldera obtained by full integration of swath bathymetry, high-resolution multichannel and single channel reflection seismics, gravity core, geochemical analysis of marine fluid vents and seafloor temperature profiling, recently acquired from the Pozzuoli Bay, along with existing geological, geophysical and geodetic datasets on land. Particularly, the high-resolution reflection seismic data offer unprecedented detailed insights into the stratigraphy and shallow structure of the NYT caldera collapse–ring fault zone–inner resurgence system. The results of this research provide a contribution to the understanding of structural style and timing of deformation of restless, resurgent calderas that develop along active continental margins.

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The applicability of isotope techniques to assess landfill leachate contamination of water resources: preliminary results from the Malagrotta (Rome, Italy) and lo Uttaro (Caserta, Italy) landfill sites

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Keywords: landfill leachate, groundwater, surface water, isotope techniques.

The prevention of pollution of groundwater and surface water bodies is a primary goal of environmental protection codes on the exercise of solid waste landfills activities (see D.Lgs. 152/06).

Hydrogeochemistry and hydrogeological characterization of water appears to be crucial for the assessment of a municipal landfill impact on groundwater and surface water. However, municipal landfills are often located in industrial areas where there are other sources of contamination such as incinerators, oil refineries, with their range of underground pipes for transporting oil and natural gas, chemical, fast roads, hazardous waste storage facilities, mining activities, as it happens at the industrial site Malagrotta (Rome, Italy) and at the lo Uttaro area (Caserta, Italy).

The presence of multiple sources of contaminants, usually used to identify losses of leachate to groundwater, such as heavy metals, chlorides, hydrocarbons, may make it difficult to interpret chemical data from monitoring wells around the landfill. In this case the use of isotopic techniques can be of great help in identifying the contamination by leachate from the landfill.

In recent years, several studies have demonstrated the effectiveness of the analysis of natural isotopes of the major constituents of landfill gas (CO_2 and CH_4) and leachate (water and dissolved inorganic carbon) in the detection of contamination of different environmental matrices at landfill sites (Liu et al., 1992, Rank et al. 1995; Hackley et al., 1996). In particular, leachate from municipal landfills usually has a characteristic isotope signature (D and Tritium) with respect to surrounding environment.

Here, the preliminary results of two case studies are reported to evaluate the applicability of isotope techniques for the identification of possible contamination of water bodies by landfill leachate. Surface water, groundwater and leachate samples have been collected at the Malagrotta (Rome, Italy) and lo Uttaro (Caserta, Italy) municipal landfill sites and analyzed to determine chemical-physical parameters, D, 18O, Tritium, major ions and trace elements. In both case studies the isotopic techniques integrated with a hydrogeological and hydrogeochemical monitoring were suitable tools to identify leachate contamination of groundwater in the vicinity of municipal landfills.

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Open-Loop Groundwater Heat Pump System: dynamic behavior and cross-correlation between the groundwater temperature and electrical conductivity

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Keywords: Groundwater Heat Pump System (GHPS), Electrical Conductivity, cross-correlation functions.

Groundwater Heat Pumps Systems (GWHPs), utilizing relatively stable groundwater temperature, are an efficient use of natural energy, can achieve a higher performance coefficient, and a thermal plume of colder or warmer re-injected groundwater, known as the Thermal Affected Zone (TAZ), develops.

The plume propagation occurs primarily through advection (Lo Russo & Taddia, 2010), and tends to "degrade" following conductive heat transport, and convection within moving water (Hecht-Mendez et al., 2010). Plumes of colder or warmer re-injected groundwater are considered a potential anthropogenic geothermal resource or pollution. In fact, a thermal plume might pose a risk to groundwater use downgradient.

This study is aimed to explore the auto and cross-correlation between some groundwater parameters (temperature, hydraulic levels and electrical conductivity) measured through specific multiparameter probes in a real field test-site. The data under consideration derived from the groundwater monitoring in the surrounding area of an injection well connected to an open-loop GWHP plant installed in the "Politecnico di Torino" (NW Italy). The plant is used for cooling some of the university buildings. Groundwater pumping and injection interfere only with the upper unconfined aquifer.

The GWHP plant is constituted by a 40-m deep pumping well (P2) and a downgradient 47-m deep injection well (P4). A 35-m deep piezometer (S2) is located downgradient respect P4. The abstraction and injection well as the piezometer are screened along the whole saturated zone of the exploited unconfined aquifer.

The continuous monitoring of the hydraulic levels, electrical conductivity EC and temperature T in P2, P4 and S2 is performed along the whole year, including the period of the switching off of the cooling plant. The analysis of correlation presented concentrates on the hourly data collected in the summer 2015. The GWHP plant started its operation on April 8th, 2015 and switch off on September, 3th 2015. Data collected in P4 and S2 are important to understand the subsurface heat transport phenomena and the possible trend between EC and T. The study of these correlations can be useful to characterize the heat transport in the aquifer and detecting the real velocity of migration of the thermal plume under the real operating conditions.

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Mercury Intrusion Porosimetry to Hydraulically Characterize Porous Rock

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Keywords: Rock Water Retention, Mercury Intrusion Porosimetry, Pore Size Distribution, Bimodal Porosity.

Hydraulic properties of variably-saturated porous media are essential for the quantitative analysis of water flow and solute transport under unsaturated conditions. Most experimental methods to determine the hydraulic functions (i.e., water retention and unsaturated hydraulic conductivity) are limited to a narrow range of water contents either in dry or in wet ranges. The aim was to characterize the water retention curves of porous rocks by employing pore-size distributions obtained with mercury intrusion porosimetry (MIP). For this purpose, two different lithotypes belonging to Calcarenite di Gravina Formation, a Plio-Pleistocene sedimentary rock of marine origin, were investigated. The two lithotypes differ mainly in texture and came from two distinct quarry districts, Canosa di Puglia (*C*) and Massafra (*M*) in southern Italy, respectively. This relatively porous rock formation often constitutes a thick layer of vadose zone in several places of Mediterranean basin. For the study 4 hand-cut core samples having 1 cm in diameter and 2 cm in height, were investigated. A Micromeritics Autopore IV mercury porosimeter was used to measure mercury intrusion (volumetric mercury content, θ_{Hg}) at applied pressures, ψ, up to 42000kPa. The results show different pore size with multi-modal porosities. Pore diameter values ranged between 0.003 and 330 µm for both lithotypes; however, two bimodal peaks diameters of 0.135 and 27.5 µm and 1.847 and 19.7 µm were exhibited for *C* and *M*, respectively. The results suggest that MIP, although its limitation in detecting both the larger pores and the very small pores (<0.003 µm), alone may suffice to describe accurately the complete retention curve in the whole θ_{Hg} range as compared to water retention curves. Moreover, the results highlight that a bimodal porosity is clearly evident for *C,* and that porosimetry yields retention curves in which θ_{Hg} for mercury retention curves is usually lower as compared to water retention curves obtained with traditional methods.

SESSION S32

Archaeogeophysics: requirement or choice?

CONVENERS AND CHAIRPERSONS

Patrizia Capizzi (Università di Palermo)
Valeria Paoletti (Università di Napoli Federico II)
Michele Pipan (Università di Trieste)
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The role of earthquakes and landslides in the destruction of Abakainon necropolis (NE Sicily): results from geomorphological and geophysical investigations

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Keywords: Electrical Resistivity Tomography, Seismic Refraction Tomography, landslides, necropolis.

Detailed geomorphological surveys combined with the analysis of aerial photographs allowed to identify some overlapped landslides on the slope of Mt. Sceti - Pizzo Cisterna, the largest of these also includes the necropolis of Abakainon that shows clear evidence of collapse and deformation. In previous years, the archaeological site has been investigated through archaeoseismological investigations in order to identify the cause responsible for the observed damage, and the results showed that the most likely cause was a seismo-induced landslide. The most frequent type of damage observed in the site refers to the columns of the funerary monument collapsed in the same direction. As a consequence of the collapse, the columns were fractured in two or more parts, causing diffuse cracks in the tomb basements and dipping broken corners. Steles and columns of some tombs have entirely fallen, while their basement is counter slope tilted (ESE dipping). Dating of colluvium samples constrained the seismic event or seismic sequence to the 1st century AD, probably during the time-span 14-37 AD as mentioned by historical sources.

An integrated geophysical survey was performed at the site in order to confirm the geomorphological evidence of some overlapped landslides and a numerical analysis of the slope under seismic loads has been performed in order to support the hypothesis of a seismo-induced cause for the destruction of Abakainon necropolis. This study improves our knowledge on the geomorphological and geological features of the site. Furthermore, the suitability and advantages of combining geological and geophysical investigation for landslide characterization has been carefully analyzed. The main goal was to reconstruct the geometry and the thickness of the mobilized materials of the landslide, on which the necropolis stands. Based on specific geoarchaeological study, indirect investigations were performed at the site through Seismic Refraction Tomography (SRT), Electric Resistivity Tomography (ERT) and Horizontal to Vertical Spectral Ratio (HVSR) microtremor. Besides, an aerial photographic survey by Unmanned Aerial Vehicle (UAV) was performed in order to map the landslide and locate adequately the seismic and electrical tomographies. Geophysical surveys were planned to provide a highly detailed reconstruction of the subsoil, verifying stratigraphic succession and lateral lithological variations. The results coming from geomorphological data combined with geophysical surveys confirm the presence of a large landslide in the studied area, and three further smallest landslides observed only by means of photo-geological interpretation.

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Geomorphological and geophysical investigations in the Roman site of Carsulae (Tiber basin, Central Italy)

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Keywords: Geomorphological evolution, geophysical investigations: ERT and FDEM, Roman archaeological site.

We present the results of the project "A multidisciplinary approach to the archaeological site of Carsulae (Tiber Basin, central Italy) for the protection of cultural heritage, landscape and environmental" that was supported by the Carit Foundation. This project aimed to improve the knowledge of the geological and lithotechnical features of the archaeological site and the surrounding territory through a geological and geophysical integrated approach.

In particular, the main goal of the present study was to reconstruct geometry and thickness of the calcareous tufa basement, on which the archaeological ruins lie; on the bedrock insists evident karst dissolution phenomena, mainly due to the erosive action of the underground waters. In the past, ground deformation related to the development of a subsidence-doline caused severe damage to some man-made structures at Carsulae. Among the dolines identified in the site, that one placed between the Consular Flaminia road and the decumanus subsided in Roman times and produced an evident and progressive sharp deformation of the decumanus.

For this purpose, the geomorphological and geophysical surveys were directed to the acquisition of shallow and deep geological data combined with the landscape and environmental analysis in the area surrounding the site of Carsulae.

Moreover, this study explores the suitability and the advantages in combining both the geological and the geophysical techniques for karst structures characterization. Based on specific and updated/revised archaeological studies, direct (sediment borings) and indirect (geophysical ERT and FDEM methods) investigations were performed at the site. The field surveys allowed the delineation of the irregular geometry of the calcareous tufa, verifying at the same time their high alteration/dissolution characteristics. Although the geomorphological and geophysical study covered a small area within the site, the results highlight a marked geological and hydrogeological instability mainly connected to the groundwater circulation.

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The use of non-invasive investigation techniques for the characterization of historical columns

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Keywords: GPR, Ultrasound, Historical columns.

All restoration projects should start from the characterization and the understanding of the state of preservation of the target to be restored. The non-invasive geophysical techniques are now a valuable diagnostic tool to support restoration work by providing a characterization of some physical parameters of material and contributing to the understanding of ancient techniques and construction methods. The objective of this work focuses on non-invasive investigations that can be performed for this purpose on historical columns. In particular the results that can be obtained from two non-invasive techniques,high-frequency ground penetrating radar and ultrasonic investigations, are compared. In both techniques you can use a tomographic approach or perform investigations of points or profiles. Furthermore the modalities of integration between these two different methods of investigation and the comparison of results obtained individually are explored and discussed. Three case studies are presented as examples.

In the first case the results of some ultrasound investigations on two monolithic columns of Palazzo Branciforte, Palermo are presented. The investigations were performed to highlight possible areas of weakness of the rock that forms the columns that still have an important supporting function for the building. In the second case the results obtained from GPR surveys on three columns of the cathedral of Agrigento, which delimit the central nave of the church are exposed. In this case the investigation had the purpose of understanding the construction methods and the type of material used because the outer surface of the columns has an ornamental layer.

Finally the results obtained with both methods on the ten columns of the Corridor of the Great Hunt of Villa Romana del Casale, Piazza Armerina are presented. The investigations were performed for locating any metal pins, for the detection of internal anomalies and delimitation of the reconstructed areas during a first restoration dates back to the period in which the archaeological site was discovered.

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A low cost customizable micro-ROV for underwater archaeogeophysics

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Keywords: Remotely Operated Vehicles, underwater archaeogeophysics, ROVER project.

Holocene sea-level rises caused the submersion of some archaeological sites along the coasts of the Mediterranean. Although these submerged sites are located to easily accessible depth by divers, within 10-15 m b.sl., underwater archeological research are generally difficult, and need of expertise and diving skills. Besides a limiting factor in underwater research dives is connected with the diving time generally confined in a short time period. Underwater archaeogephysics can be considered a complementary tool to the archaeological researches for deep and shallow sites. In these cases, beyond the reach of divers, submarines or remote sensing equipment are required. Remotely Operated Vehicles (ROV) are underwater vehicles operated from the surface able to integrate diver's surveys. ROV dives combine with those of specialized dive operators both because researchers can observe in real-time what the ROV sees through its cameras and because ROV can reach depths excluded to scuba divers. In the framework of the ROVER (Remotely Operated Vehicle for Environmental Research) project, funded by the Volcano Division of the Istituto Nazionale di Geofisica e Vulcanologia (Italy), we have realized a low cost micro-ROV (Class <3 kg). The micro-ROV developed is based on open-source philosophy of the OpenROV system (www.openrov. org). Vessel, payload and electronic features are completely open to improvements and third-part add-ons. The submarine vehicle has been realized to reach the maximum depth of 100 m and at the same time to be easily drivable in small spaces by means of depth-constant navigation system. This navigation mode allows the operator to steer the robot along a plane at constant depth, and it uses information from the on-board depth sensor to correct the motion if it deviates from this plane. The ROV was also equipped by an inertial measurement unit, a compass and a depth sensor to achieve a controlled navigation system. For the purposes of archaeogeophysics, the microROV was equipped with HD camera a high-speed 3-axis fluxgate 24-bit magnetometer. Early tests in pool, harbour and several test sites, given promising results for the use of such low cost micro-ROV for underwater archaeogeophysics.

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Decrease of hazards within development projects by a multi-criteria approach; from archeology to modern pollution

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Keywords: archeology, modern pollution.

Through the example of several big development projects in France, we show the use of a set of high-resolution techniques (with infra-metrics spatial resolution) that allows establishing a global non-destructive assessment over a given site and thus a decrease of hazards for the future construction sites. This approach was first introduced for projects of URBAN DEVELOPMENT ZONES in the 2006s by Géocarta under the name of "approach ZSCAN" and then extended to linear projects afterwards (highways, corridors). To do it, advances concerned at first field instrumentation. This one was redeveloped for the various techniques (electric, magnetic, electromagnetic) in such a way to be easily deployed from an equipped truck and using accurate real-time positioning of sensors. The speed, but especially the density of measurements was favored to reach an infra-metric spatial scale, a necessary spatial resolution in all the studies of the first meters of the sub-surface. Since 2010, facing the problems of management of the complexity of certain projects of development, a collaborative platform (Web-GIS) was developed. This one allows the display, the distribution and the interpretation of the data for the different stakeholders within complex projects. We show several examples where the archaeological hazard (risk) was able to be anticipated without passing by a destructive phase with mechanical excavators. Besides, geophysical prospection allows in certain cases to help the archaeologist in the various phases of the archaeological operations: before the diagnosis, after the diagnosis during the phase of prescription by the services of the State, during the phase of excavation to help the archaeologist and finally post-search 'to follow' the archaeological structures outside the footprint of the project. Beyond the archaeological hazard, we show that same geophysical maps can be used for the consideration of hazards cavities, in particular linked to battlefields in the North of France; pyrotechnic hazards as well as various hazards over sites and polluted grounds.

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Three-dimensional electrical and seismic tomography for assessing the state of conservation of a masonry wall

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Keywords: electrical resistivity tomography, seismic tomography, masonry wall, rising damp.

Geophysical non-destructive testing has been applied worldwide during last decades for understanding the inner geometry, the constructive materials and the degree of conservation of ancient buildings affected by the ravages of time, human interventions or natural phenomena (e.g. Polymenakos et al. 2005; Tsokas et al., 2013).

The integrated approach presented in this work encompasses the use of Electrical Resistivity Tomography (ERT) and seismic tomography aiming to assess the current state of conservation of a Roman masonry building, named "Casa di Diana", located at the Ostia Antica archaeological site (Rome, Italy).

Three-dimensional ERT and seismic tomography investigations were focused on an inner wall, made in opus caementicium, prone to both rising damp and cracking phenomena, in order to reconstruct a 3D model where anomalous zones would be highlighted. ERT dataset were inverted with the VEMI interface (De Donno & Cardarelli, 2015), while seismic tomography inversion was performed by means of the algorithm after Cardarelli & Cerreto (2002).

Results show that low resistivity and P-wave velocity values can be associated to the presence of the inner mortar, while higher values of both parameters were observed for the existence of the outer brick component. Overall, with reference to a previous work where a small-scale sample of a Roman masonry wall was analysed in the laboratory using seismic tomography (Cardarelli & de Nardis, 1999), the brick part seems to be in good conditions (optimal V_P=1400 m/s, recovered V_P=1300 m/s), while the low velocity values of the mortar (optimal V_P=500 m/s, recovered V_P=250 m/s) can potentially represent an anomaly due to degradation phenomena. Therefore this approach can be employed to reconstruct a 3D model of an archaeological wall in order to plan the recovery actions.

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Contribution of geophysical methods to the characterization of the subsoil at archaeological seismic sites: the case of Hierapolis (Turkey)

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Keywords: soil characterization, seismic site, GPR, ERT, reflection seismic surveys, surface wave analysis.

The characterization of the subsoil, particularly in active seismic zones, is fundamental to plan the activities and the tools to be adopted for heritage preservation. In this context, the use of geophysical measurements, considering their non-invasive approach, offers an essential contribution to localize the anomalies in the subsoil, identifying the most critical zones under the built heritage. We present an example of soil characterization in a seismic zone represented by the results of geophysical surveys carried out at the archeological site of Hierapolis (Turkey). The goal is to reconstruct the subsoil characteristics under a monumental building known as 'Terme-Chiesa' complex, exposed at serious seismic damages through many centuries. The Hierapolis archeological site is located on the complex Eastern normal faults system of the Denizli Graben (De Filippis et al., 2012). The site was interested by a dozen of large earthquakes in the last few centuries. The faults system that crosses the archeological site is considered "seismogenic", i.e. being capable of seismic magnitude > 6.0 (Hancock et al., 2000). The normal fault system, on the other hand, facilitates spontaneous thermal springs exploited since the Roman period, where the rising of hot carbonatic waters facilitated the deposit of thick travertine covers (Ozkul et al., 2013; Koralay & Kılınçarslan, 2015). This peculiar and complex geological context made the fortune of the ancient Hierapolis, worldwide known for its travertine quarries, but it should be carefully taken in account for seismic response. On the other hand, one should note that large travertine deposits, highly conductive in term of electrical properties, can affect geophysical results (e.g. Pola et al., 2014). For the characterization of the 'Terme-Chiesa' subsoil at Hierapolis, we used GPR and ERT measurements, reflection seismic surveys, surface wave analysis and passive seismic acquisitions. In the end, the subsoil characterization by geophysical measurements shows close correlations with structural damage evaluations and offers new tips in the field of built preservation.

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Research of crypts and/or cavities of the Bronze Age in the Hyblean carbonate soil by means of seismic tomography: a case study

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Keywords: Cava Ispica, bronze age, seismic tomography, cavities, Sicily.

The Hyblean plateau (South Eastern Sicily) consists of a platform carbonate interbedded with volcanic horizons, whose age ranges from the Cretaceous to the Pleistocene and is characterized by the presence of numerous incisions from waterways, known locally as "hollow". The most important is the “Cava Ispica” which crosses for about 13 km the municipalities of Modica, Ispica and Rosolini. It is a collection of archaeological evidence, ranging from prehistoric to medieval low, entirely cut into the rocks, which make this "hollow" one of the most representative historical places of Sicily pre-classical and late antiquity (Trigilia, 2011). The monuments that are within the perimeter of the Regional Archaeological Park have long been excavated, but many still remain below the current floor plans due to the amount of coves that characterizes this part of Modica territory. Non-invasive seismic surveys were carried out in the area between the catacomb of Larderia (IV-V century a.d.) and the area of the Gymnasium’s caves (III century b.c.) in order to identify the possible presence of anthropic cavities in the subsoil.

The strong contrast between the low velocity zones such as human cavities, and high seismic velocity waves of limestone rock formation that contains them, strongly favors the use of this geophysical technique (Cardarelli et al., 2010). As witnessed by the numerous excavations carried out in the area during the archaeological surveys the cavities are often filled by material of geological/anthropogenic source that has accumulated in hundreds of years, this means that there is not a sharp contrast between the rocky continuum and the empty.

The seismic refraction surveys processed using tomographic method have highlighted low seismic velocity (<400 m/sec) zones distributed evenly in both areas on the site "Gymnasium" and "Terrace", with constant depth of two meters from the surface. These areas represent evidence of the presence of man-made cavities. The size and the shape of cavities have been defined through the isovelocity surface having values of about 400 m/sec. On the basis of knowledge acquired the shapes and sizes of these areas are compatible with paleo-anthropic elements present in the site and visible on the surface, and it is therefore reasonable to expect similar deep structures.

The three-dimensional reconstruction doesn’t highlights a net and linear geometry, because, as is expected, can be filled largely by solids.

Although the lack of a net velocity contrast between the rock and the filled or partially filled cavities has made difficult to interpret the seismic lines acquired, the numerous informations deriving from surveys carried out are undoubtedly a useful planning tool for the purposes archaeological research.

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Geophysics applied to archaeology: multi-instrumental surveys for a Byzantine site recovery in Eastern Sicily

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Keywords: geoarcheology, multidisciplinary approach, multi-instrumental surveys.

In recent years the geophysical applications in archaeology allowed the archaeological research to program /optimize phases of archaeological excavation of any target, although today there isn't an universal method of geophysical survey for all types of contexts. This note presents the case-study results in an archaeological site in Ragusa province, obtained by investigations performed with multi-instrument and multidisciplinary approach (archaeology, geology, geophysics and topography), focused on the context characteristics and research objectives. The case-study is a late Roman – Byzantine site in C.da Selvaggio (Rg), marked by a small thermal bath and a Tardo-Antica church; geophysical surveys conducted here have had a dual purpose. The first, properly about research and study, verifying archaeological assumptions respect to a structure covered by a late medieval adamant pavement. The results of the geophysical surveys have enabled us to detect the presence of voids below the pavement that, when excavated, has been revealed as tombs; while the second, provided the certainty of the presence of buried structures (potential alignments of walls and roads) useful to program possible further excavations next the Frigidarium (part of the old small thermal bath) already identified.

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Integrated geological and geophysical methods to investigate the Palatine hill archaeological area (Rome, Italy)

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Keywords: Integrated subsurface model, Anthropic layer, ERT and GPR, Geohazard assessment, Palatine hill.

The Palatine hill archaeological area was investigated with the aim of assessing local geohazard levels. In particular, well-logs from continuous coring boreholes, Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) surveys were integrated in order to detect cavities, both in the geological units and in the anthropogenic layer.

Continuous coring boreholes were drilled on the Palatine hilltop, along the slopes, and in the alluvial valleys bordering the hill. All the boreholes crossed the anthropic layer, which ranges in thickness between 1 and 20 meters. Some of the boreholes drilled built structures with empty voids, or filled by anthropogenic material. Several boreholes also crossed a network of tunnels dug in the tuff rocks underlying the anthropic layer. These tunnels are often filled with unconsolidated, unsorted anthropogenic material.

For the GPR surveys, a GPR SIR3000 (GSSI) equipped with a 500 MHz bistatic antenna with constant offset, a 70 MHz monostatic antenna, and a 35 MHz monostatic antenna, was employed. A nominal microwave velocity of about 0.07 m ns-1 was determined from fitting hyperbolas to the raw field data and used to estimate the penetration depth from the GPR survey (up to approximately 15 meters). In order to obtain a planimetric image of all possible anomalous bodies, the time-slice representation technique was applied using all field profiles.

GPR survey was than constrained mainly using well-logs and archaeological stratigraphies. Low intensity reflectors are related to fine-grained geological and anthropogenic materials, while high-intensity reflectors are referred to empty voids and to masonry or foundation remains.

Resistivity field data were collected with a Syscal R2 resistivity meter coupled to a multielectrode acquisition system (48 electrodes), using different array configurations (Wenner-Schlumberger and Dipole-Dipole) and an electrode spacing ranging from 1 to 10 m, obtaining different investigation depth (from about 8 to 80 m).

The electrical images were successively compared and calibrated with data coming from geological, archaeological, well-logs and GPR surveys. As regards the archaeological layer, it shows an irregular lower boundary and variable resistivity values. Relatively high resistivity values (ρ>400 Ωm) are associated to voids and/or cemented conglomeratic walls, while low to moderate resistivity values (ρ Particular attention was paid to two areas of the hill, i.e., the Clivo Palatino and the so-called No Man's Land. Integration of information resulting from different prospecting techniques have allowed us to define an extremely complex subsoil setting, mainly due to the presence of cavities whose partial collapse has probably involved built structures already in historical times, as well documented by the archaeologists in this area of the hill.

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Integrated Geophysical Investigation of a Buried Roman Villa in Pompeii

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Keywords: Electric and Seismic Tomography, Magnetometric Survey, GPR, Rural Villa, Imperial Age.

In archaeological research non-invasive techniques are commonly used to characterize a site or part of it. Among them, geophysical surveying is a valuable, non-destructive tool for archaeologists in evaluating sites and guiding excavation programmes within already discovered sites.

In this paper we describe the results of an integrated geophysical survey carried out over a buried Roman Villa in Via Nolana, Pompeii. The area was partially unearthed in 1985 showing the remnants of a villa from the first Imperial Age. The excavation found also some frescos and traces of rural activities. The remnants were successively earthed again.

The survey included high-resolution Geoelectrical, Magnetometric, Seismic and Ground Penetrating Radar measurements. They were performed both over the known buried structures and in the unexplored area immediately adjacent to the remnants, with the aim of verifying the presence of other unearthed villa structures beyond the explored area.

Data processing included advanced filtering techniques, such as *Discrete Wavelet Transform* (DWT, Fedi & Florio, 2003), allowing an effective filtering of localized and directional noise. Furthermore, the use of multi-scale potential-field techniques such as *Enhanced Horizontal Derivative* (EHD; Fedi & Florio, 2001) and *Depth from Extreme Points* (DEXP; Fedi, 2007) allowed positioning the lateral edges of the buried structures and characterizing their shape and depth.

The results yielded by the different methods showed a rather good consistency in terms of position and size of the buried structures. Furthermore, the integration of the outcome of each geophysical technique reduced the intrinsic ambiguities of each method.

Our interpretation revealed the presence of remnants in the unearthed area, in continuation of the already discovered section of the villa, and highlighted preferential areas for future archaeological diggings.

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First outcomes on the study of a relict landslide at the Abakainon necropolis (NE Sicily)

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Keywords: Relict landslide, Abakainon, seismic tomography, necropolis.

The Greek colony of Abakainon was a founded in northeastern Sicily by Sicels, after having defeated the Sicani in 1100 BC (Oliva et al., 2012). Its strategic location made this settlement very desired, especially for military and trading purposes, leading to a succession of conquests by different people. Nowadays, the unearthed ruins of the necropolis are accessible to tourists at the village of Tripi, northern Sicily. Here several tombs appear partially collapsed or broken, probably due to a natural event. An archaeoseimological study was carried out by Bottari et al. (2013), who found that the necropolis was abandoned before the collapse, and that the destruction is likely to have occurred after an earthquake. In particular, from in situ morphological evidences they hypothesized that the necropolis was built on a relict landslide, which is likely to have been reactivated by the seismic event, leading to the destruction of the site.

This research aims to investigate on the landslides occurred in this area, looking for evidences of the relict landslide hypothesized by Bottari et al. (2013), by in situ geological and geophysical surveys. Several landslide bodies were surveyed in the area, along with widespread blocks fallen from rock cliffs. The main movements can be classified as rockfalls, debris flows and rotational or planar sliding and affect both the intensely weathered metamorphic basement and its sedimentary covers. With particular reference to the necropolis site, electric and seismic tomographies were performed looking for evidences of the main body of the relict landslide. Results highlight that the necropolis was built on a poor material from a geomechanical point of view, with P-wave velocity lower than 800 m/s and low resistance values, comparable to material mobilized by an old landslide. The lowest seismic velocities characterize the central sector of the site, which is likely to be the midmost portion of the main body of the relict landslide. Nevertheless, within the investigated depth (about 17 m) no sliding surface was detected; for this reason, further surveys will be soon performed.

Achieved results, although preliminary, validate the hypothesis that the Abakainon necropolis was built on a relict landslide body and that, after a shaking event, it was razed probably due to a site effect.

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Searching for the Antigonea theatre: A magnetic survey in an ancient Epirus city

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Keywords: Magnetic anomalies, Topographic correction, Greek theatre, Albania, Antigonea.

We report on two magnetic surveys performed in July and September 2015 at the ancient Hellenistic city of Antigonea, located in southern Albania. The main objective of the two surveys was to find the city theatre and determine possible sites of future excavations. We developed a new technique for dense collecting of magnetic data along difficult terrains, with minimization of the topographic effect. Evidence of a possible location of the theatre was found along the southern slope of the Jermë hill, just outside the city walls. Other interesting structures indicate the presence of many other buildings in this part of the Antigonea settlement.

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Magnetic and electromagnetic prospections at the Roman city of Urbs Salvia, central Italy

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Keywords: Magnetic anomalies; Urbs Salvia; Forum; Ground Penetrating Radar.

We report on a combined magnetic–GPR survey performed in 2015 and 2016 at the ancient Roman city of Urbs Salvia, located in central Italy. The main objective of this survey was to reconstruct the urban organization of the city forum and determine possible sites of future excavations. We found a complex pattern of buried structures, possibly resulting from the coexistence of republican and imperial artifacts and burned structures. A test excavation at the location where we detected a long linear structure characterized by strong magnetic signal revealed the presence of thermal baths. GPR data were acquired in the area adjacent to the theatre and in other areas characterized by high magnetic noise induced by metallic infrastructures (e.g., fences), which prevented a correct acquisition of archaeological anomalies. These data not only allowed to overcome the magnetic noise, but provided interesting 3D reconstructions of the buried structures.

SESSION S33

Metals in the Mediterranean area: Archaeology and current resources

CONVENERS AND CHAIRPERSONS

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Nicola Mondillo (Università di Napoli Federico II)
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Prehistoric copper exploitation in the Alps

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Keywords: Copper metallurgy, Alps, Copper Age, Bronze Age, smelting slags, mining.

The research group at the University of Padova has developed a geochemical database for the Alpine copper mines that includes lead isotope data for most of the copper deposits in the Western Alps and Italian Eastern Alps, besides a number of other geochemical tracers for selected deposits. The database fills an existing gap in available reference data and provides valuable information for the geochemical interpretation of the mineral deposits. The database may be critically inquired to assess the provenance of the mineral source of slags and metal objects: The successful results obtained on provenancing a number of Copper Age and Bronze Age metal objects will be presented. The data clearly show the importance of the Alpine deposits in the production and circulation of copper metal in prehistoric and protohistoric times. The chemical and isotopic differences between Bronze Age copper ingots and coeval metal objects are discussed.

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"Critical" importance of the Silius vein system (SE Sardinia,Italy)

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Keywords: Fluorite, Rare Earth Elements, critical raw materials.

The late- to post-Hercynian geological evolution of Europe, as well as part of Northern Africa, is characterized by numerous hydrothermal mineralizing events, ranging in age from the end of the orogenic compression (Permian) to the onset of Tethys spreading (Triassic-Jurassic) (Muchez et al., 2005). The Silius vein system (SE Sardinia (Italy) is analogous to other late- to post-Hercynian mineral systems of this type in Europe. Silius consists of two main veins, characterized by several generations of fluorite, barite, carbonates and quartz (Boni et al., 2009). Silius is known for its barite-fluorite, but also galena mineralizations that have been exploited until lately. Distinct fluorspar resources still exist in the mine area. Gangue carbonates, consisting of calcite and ferroan dolomite, contain Rare Earth Elements (REE)-bearing minerals represented by minor xenotime, and especially by synchysite-(Ce) (Mondillo et al., 2016).

To check the effective amounts of REE in the Silius orebody, representative samples of the carbonate gangue have been collected in the underground mine. The values of LREE mainly, are in the range of 462-2071 ppm (951 ppm on average). The average volume of the carbonate gangue still in place is considered to be around 532,000 tons, to which may be added more 750,000 tons of carbonates discarded at the flotation plant. The corresponding total REE resource currently occurring at Silius may be about 1,220 tons.

The discovery of REE in the Silius mine opens interesting perspectives for the exploration of subeconomic REE concentrations in this deposits type, where REE could be recovered as by-product of the fluorite exploitation. REE geochemistry of carbonates in other post-Hercynian fluorite veins has been widely investigated in the Harz Mts (Germany), in the Valle de Tena (Spain) and in the El Hammam orebodies (Morocco). Even though REE occur in contents comparable to those observed at Silius, the above deposits are not considered economic for this type of commodity till now. Being both REE and fluorite critical raw materials for the European economy, the Silius and the other similar post-Hercynian F-mineralizations should be now reconsidered in their double significance: not only for their fluorspar content, but also for the possibly recoverable REEs contained in the carbonate gangue.

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Metallic artifacts (Bronze/Iron Age, Campania region, southern Italy) from the collection of the Paleontological Museum of the University of Naples Federico II: a first look

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Keywords: bronze, objects, Bronze/Iron Age, Striano, Sarno River plain, Campania, mineralogy.

Archaeological metallic objects coming from the Striano surroundings, a town located in the Sarno River plain (Campania region, southern Italy), are preserved in the Paleontological Museum (Centro Musei delle Scienze Naturali e Fisiche) of University of Naples Federico II. They belong to a vast collection of ceramics and metallic artifacts, found in 1930 and then given to the former Geological Museum of the Naples University (De Joanna, 1947). These objects are related to the proto-historic necropolis of Striano, that date back to the late Bronze Age up to the Iron Age ("Orientalizing" period; D'Ambrosio et al., 2009). These findings are very common in the whole Sarno River plain, situated in the south of the Somma-Vesuvius volcanic complex. Until today the archaeological research activity of the Sarno River plain was particularly focused on urban settlements like Pompeii, Nuceria and Stabiae, but all their hinterland represents a very important cultural landscape, characterized by continuous anthropogenic activity since the Middle Bronze Age (Seiler et al., 2010). The eruption of the Somma-Vesuvius AD 79 resulted in a nearly complete burial of the entire Sarno River plain, hence this unique situation of a sealed pre-AD 79 perfectly conserved archaeological findings and paleo-landscape enable detailed investigations of both the ancient remains of human activity in the plain and of the paleo-environment/topography (Seiler et al., 2010). The metallic objects consist of bronze spearheads and sheaths, and have never studied before. This work deals with a first mineralogical characterization of the bronze artifacts by means of X-ray powder diffraction (XRPD), metallographic optical microscopy and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS). Preliminary mineralogical data show that they are mainly composed of Cu-Sn alloy, with Sn content ranging from 5 to 12 %. Inclusions of galena, native copper, lead and silver, as well as argentite are also detected in the alloy. Alteration minerals are mainly represented by cuprite, silicates, phosphates and sulfates. Microstructures are observed by optical microscopy and secondary/backscattered electrons imaging.

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Mineralogical and geochemical data on metallic artifacts from the National Archaeological Museum of the Agro Picentino – Pontecagnano (Salerno)

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Keywords: metallic objects, Pontecagnano museum, Bronze Age, Iron age, IV-V century.

Pontecagnano (SE of Salerno) archaeological site, the ancient town of Amina (renamed "Picentia" by the Romans) is the largest Etruscan outpost in the south (Camporeale, 2013; Cerchiai, 2013; Cuozzo, 2013). Archaeological investigations - started since the 1960s - certify the area has been inhabited as early as late Neolithic. At the beginning of the 3rd millennium BC the area was settled by peoples of Gaudo culture, probably immigrated from Anatolia. Gaudo population worked metals, as testified from copper daggers and other weapons excavated from more than 9.000 tombs in the area. The National Archaeological Museum of the Agro Picentino was instituted in 2007 and contains more than 8000 findings mainly related to tomb outfits (Tocco, 2007). The main Etruscan settlement was founded between the end of the X and beginning of IX century b.C. on the left side of the Picentino river. The period of its greatest development was the "Orientalizing" age (end of VIII-VII century b.C.), when great and wealthy aristocratic families (the so-called "Princes") took the power, as also testified by precious artifacts found in the Pontecagnano burials. Then, the settlement took urban connotations, becoming a frontier community. This work deals with mineralogical and geochemical characterization of various metallic artifacts spanning in age from early Eneolithic/Bronze Age to IV century b.C. by means of X-ray powder diffraction (XRPD), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) and micro X-ray fluorescence m-XRF. The objects are of different types (fibulae, rings, earrings, spears, pins, ingots, slags, etc.), and are mainly composed of lead, copper, silver and bronze. The bronze artifacts are high-Sn (17.3 to 27.4 %, Sn), as expected by ancient alloys; lead and iron, as well as titanium and nickel to a lesser extent, can be also present as minor to trace components. The silver artifacts can contain small amounts of copper, iron and gold; in one case a copper object (91.4 % Cu) also shows other metallic components, as lead (4.8 %), bismuth (2.6 %) and iron (1.1 %). Interesting microstructures are also observed. Finally, the combined use of two spectroscopic techniques allowed us to verify the potential of m-XRF in archaeometallurgy sector in order to carry out non-destructive and non-invasive analyses.

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Image analysis on bauxitic ores: he case of Southern Italy karst bauxites

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Keywords: Karst bauxites, Southern Italy, Image analysis, Fractal dimension, Significant correlation.

Karst bauxites are supergene residual ores mainly composed of Al- and Fe- oxy-hydroxides formed in tropical to sub-tropical climates (Bárdossy, 1982). Southern Italy karst bauxites are located in Apulia and Campania regions. In Apulia there are the autochthonous deposits of Spinazzola (Murge) and San Giovanni Rotondo (Gargano), as well as the allochthonous Salento-type deposits, while Campania bauxites are located in the Matese Mts and in the Caserta area. Both Apulia and Campania regions, during Cretaceous, experienced sub-aerial carbonate exposure promoting bauxite accumulation (Bárdossy et al., 1977; Bárdossy 1982; D'Argenio et al., 1986; Boni et al., 2013). The texture of Southern Italy karst bauxites is mostly ooidic and consists of subcircular aggregates dispersed in a fine-grained matrix. The autochthonous bauxite ooids consist of a large core of Al-hematite surrounded by alternating layers of boehmite and Al-hematite reflecting dry and wet climate periods (Mongelli & Acquafredda, 1999; Mongelli, 2002; Mongelli et al., 2014). Allochthonous Salento-type bauxite ooids are made of a large boehmite core surrounded by a thinner Al-hematite rim (Mongelli et al., 2015). Image analysis was performed on several karst bauxite deposits, and provided geometric data such as ooids circularity and aspect ratio, number of ooids and fractal dimension D. The arrangement and the growth of the ooids can be described with a molecular diffusion pattern based on the first Fick's law, and their growth can be described with fractal geometry, assuming the ooids as fractals (Mongelli et al., 2016). The D values for the Apulia bauxite deposits are close to values associated with experimental diffusion-limited aggregation (DLA) models ($D = 1.62 \pm 0.4$; Meakin, 1991), while the fractal dimension of the Campania deposits is higher than those of the Apulia bauxites and close to the fractal dimension associated with the diffusion-limited cluster aggregation processes ($1.75 \leq D \leq 1.80$). These differences suggest that during long-lasting sub-aerial events, the diffusion-limited cluster aggregation processes can prevail over the simpler diffusion-limited, which is responsible for ooids formation during time-limited exposure events. Significant positive and negative correlations between image analysis results and compositional data were observed in the studied karst bauxite deposits. In the allochthonous Salento-type deposit significant correlations between geometric features (number of ooids and aspect ratio) with some critical elements (Sc, Ni and REEs) has been observed. In the autochthonous Apulian bauxite deposits a significant correlation between Ni and circularity has been observed. Image analysis and its integration with other analytical techniques provide interesting informations about bauxite deposits formation, and can represent an innovative useful tool for the exploration of bauxitic ores.

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Database of geological, archaeological and mining research in the southeastern province of Livorno. Analysis of the mining activities of pre-industrial age compared by the current exploitation

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Keywords: etruscan period, geo-referenced database, karst phenomena, mining archaeology, pre industrial mining.

The mineralizations embedded in carbonates outcropping in the southeastern province of Livorno have always been an important and strategic economic resource for the population of these areas: they were in fact exploited since the proto-historic period to the end of the 70s of XX century for the extraction of copper, lead, silver, iron, zinc and tin. To date, the mining activities are ended, only the extraction of stones and feldspar remains active.

This area is characterized by a main apenninic's horst, oriented N-S, formed by "Calcare Massiccio" and marginally by geometrically higher formations of the Tuscan Nappe (Costantini et al., 1993). The horst was later subjected to magmatic-hydrothermal and karst phenomena of the Neogene-Quaternary age (Cascone, 2000; Dini et al., 2013; Da Mommio et al., 2010). The first magmatic event was due to the intrusion the monzogranite of Botro ai Marmi 5.7 M/Years (Serri et al., 1993) followed by volcanic and subvulcanic bodies (Costantini et al., 1993; Poli et al., 2003). At this magmatic-hydrothermal system are related the present mineralization and skarn (Vezzoni et al., 2016; Da Mommio et al., 2010 and Dini et al., 2013th), often associated with sulfides, oxides and native elements such as Fe, Au, Cu, Pb, Zn, W, Mo and Sn.

Archaeological surface surveys identified about 200 entrances of pre-industral mining activities whose underground development is mainly vertical, clearly related to the local geo-structural order. Mines-caves can reach over 100 m difference in height and more than 500 m of length.

The presence of karst phenomena has contributed to shaping the existing mixed underground formations (caves and mines). The geological and mining-archaeological surveys of about 50 mines-caves helped to defined a methodology of study that allowed the researchers to analyze the exploitation and the transportation of ores, the organization of mining work and the chronology of the activities from the Etruscan period (VII century BC.) to the sixteenth century, allowing to place in relation the dynamics of settlement of the territory to the mining areas/activities (Cascone, Casini 1998). The data are organized in a geo-referenced database.

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Nickel-Cobalt lateritic deposits and bauxites of the Tethyan belt

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Keywords: Bauxite, Ni-Co laterite, Tethyan belt.

Laterites are regoliths developed under tropical to sub-tropical conditions and are host to key deposit types, notably bauxites (major sources of Al) and Ni-Co laterites (González-Álvarez et al. 2016). Bauxite develops from weathering of alumino-silicate rocks whilst the weathering of ultramafic rocks leads to formation of Ni-Co laterites. In the western Tethys, bauxites and Ni-Co laterites developed during the Mesozoic into Cenozoic times when geology, palaeogeography and climate were ideal for the deep weathering of favorable lithologies. Bauxites were developed on the rocks forming the continental margins to the various branches of the Tethys ocean and were already forming in Triassic times, whereas the Ni-Co laterites developed on fragments of obducted ophiolite from the Tethys ocean, which were only uplifted and exposed for weathering after the Jurassic. In situ lateritic bauxites are known in the region but karst bauxites are much more common. Ni-Co laterites are found as in situ profiles but also as distinctive, and extensively redeposited nickeliferous iron ores. The bauxite belt extends from Spain in the west, includes the type locality of Les Baux in France, and runs intermittently all the way through the Balkans, Greece and Turkey to Iran and beyond. Bauxite resources in Europe constitute around 2% of world's current known stock. Significant Ni-Co laterites are found in a more restricted geographic area stretching from Serbia through to Turkey. The bulk of both Al and Ni-Co production currently comes from Greece, today accounting for around 1% of world production of both Ni and bauxite with other mines in Turkey, Albania and Kosovo. Ferronickel plants are located in Greece, but also in the Former Yugoslav Republic of Macedonia (FYROM) and Kosovo. Primary Al is produced from local bauxite in both Greece and Turkey. The region has significant potential for further bauxite deposits although these tend to be karst bauxites developed as irregular pockets, less-suited to large-scale mining efforts. The published resource base of Greece is in the order of 650 Mt @ >50% Al_2O_3. Many undeveloped Ni-Co deposits are recorded through the region, with a recent focus on unlocking the potential of limonitic mineralization using novel hydrometallurgical technologies. Particularly noted is the potential for large low-grade redeposited lateritic Ni-Co-iron ores: Mokra Gora, Serbia, for example has a geological resource of more than 1 Gt @ 0.7% Ni, 0.05% Co. New technological advances in mineral processing could make the region more attractive for Ni but also for the co-recovery of other useful metals such as Co and Sc, which have been neglected by former and current mining operations.

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The Campo Felice and Monte Orsello bauxite occurrences (Abruzzi, Italy)

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Bauxite deposits were largely exploited in Italy at the beginning of the 20th century up to the 2nd World War. The most productive districts were located in the Gargano peninsula, in the Murge and Salento (Apulia), in Campania and in the Abruzzi region. The Abruzzi bauxite district comprises several deposits, which are currently uneconomic, in the Campo Felice, Monte Orsello and Monti D'Ocre areas (Apennine Mts.). Similarly to other mineralizations of southern Italy, the Abruzzi occurrences belong to the karst-type bauxites located along a Late Cretaceous hiatus within a Bahamian-type carbonate platform succession (Bárdossy et al. 1977). Two main bauxite horizons can be recognized: a first corresponding to a Late Albian-Early Cenomanian stratigraphic gap and a second bounded by Late Cenomanian-Early Turonian limestones (Chiocchini et al. 1994). The most prominent deposits occur in the Campo Felice and Monte Orsello areas, in the first of the mentioned gaps. These bauxites (which are the object of this study) form large lenses up to 10 m thick and more than 50 m wide.

The textures of the Abruzzi bauxites range from oolitic-pisolitic to arenitic-conglomeratic. Boehmite is the main mineral, but gibbsite has been detected in trace. The most abundant Fe-mineral is hematite, followed by goethite and lepidocrocite (rare). Kaolinite is also widespread in all the deposits, and is particularly concentrated in the matrix between ooids. The Ti-minerals anatase and rutile are ubiquitous, as well as the detrital trace minerals monazite, xenotime, zircon, baddeleyite, and ilmenite. Pyrite has been detected in the nuclei of some ooids. In few samples, cavity-filling autigenic REE Ca-fluorocarbonates have been observed. Major, minor and trace element analyses have shown that these bauxites are not only mineralogically, but also geochemically similar to those of the Matese Mts. and Caserta district, being characterized by: ~ 55 wt.% Al_2O_3, ~ 20 wt.% Fe_2O_3, ~ 10 wt.% SiO_2, ~ 2 wt.% TiO_2, Sc ~ 60 ppm, V ~ 270 ppm, Cr ~ 240 ppm, Ni ~ 200 ppm, Co ~ 35 ppm, Zr ~ 500 ppm, Ga ~ 60 ppm, Y ~ 80 ppm, and ΣREE ~ 640 ppm.

The textures, mineralogy and geochemistry of the Abruzzi deposits suggest a continuous reworking of evolved lateritic soils, which were progressively mechanically concentrated in karstic depressions where they were further subjected to local chemical weathering.

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Critical metals distribution in Tethyan karst bauxite: the Cretaceous italian example

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Keywords: Critical metals, karst bauxite, Cretaceous.

Mineral supplies have become a global concern and, within this frame, the value of bauxite ore might be possibly increased. The latest European Union report on critical raw materials listed many elements, some of which are usually found in bauxites. Gallium is a common by-product of Al extraction, and bauxites are also considered possible resources of REEs and Sc. Consequently, more attention has been recently paid to the processes that control the distribution of several minor elements in these deposits. With this in mind we present the factors affecting the distribution of the trace metals Sc, V, Cr, Co, Ni, Ga, Y, Nb, and REEs in Cretaceous karst bauxites deposits distributed across southern Italy and Sardinia.

The deposits have been extensively studied in recent years (Mameli et al., 2007; Mondillo et al., 2011; Boni et al, 2013; Mongelli et al., 2014, 2016) providing a large textural, mineralogical and chemical data-set (n=103). All bauxites share the same texture consisting of sub-circular aggregates, mainly formed by boehmite and hematite, dispersed in a fine grained matrix and are mostly composed of four major oxides: Al_2O_3, Fe_2O_3, TiO_2 and SiO_2. Among the trace metals Cr (median=547 ppm), ΣREEs (median=489 ppm), V (median=405 ppm), and Ni (median=200 ppm) are those with the highest content.

R-mode factor analysis was performed (on the whole dataset, including the outliers) in order to evaluate inter-elemental relationships. Five factors explain 81.3 % of the total variance showing significant relationships including V, Sc, Ce, and LREE (F1, 25.6 Var %), TiO_2 and Nb (F2, 22.3 Var %), SiO_2, Al_2O_3, and Ga (F3, 13.5 Var %), Fe_2O_3 and HREE (F4, 11.6 Var %), and finally Co and Ni (F5, 8.3 Var %).

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Rare Earth Elements in Pliocene Phosphorites from the Salento Peninsula, southern Italy

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Keywords: REEs, phosphorite, Salento Peninsula, Pliocene.

The Rare Earth Elements (REEs) are a group of closely related metals, from La to Lu, to which Y and Sc are usually included because of their chemical similarities and tendency to be found in the same deposits (Kesler and Simon, 2015). Furthermore, the REEs' critical role in the production of high-tech devices has increased their global demand addressing the research toward new sources on a global scale.

Sedimentary phosphate deposits (phosphorites) can be significantly enriched in REEs (e.g. Emsbo et al., 2015; Keciched 2016) and nearly 100% of total REE content can be extracted showing that the extraction of REEs from phosphorites is not subject to the technological and environmental challenges affecting the exploitation of many REE deposits (Emsbo et al., 2015).

We present for the first time, after an early paper of Agus and Alfano (1981) devoted to a possible phosphorous exploitation, a comprehensive study about the REEs' distribution in a phosphorite level in the southernmost part of the Salento Peninsula, southern Italy. The level occurs within shallow water calcarenites and calcareous organic sands (Uggiano Ia Chiesa Fm, Pliocene). The phosphorite levels are formed by brownish and rounded phosphate-rich aggregates (1-5 cm in size) embedded within a glauconite-rich matrix. The nodular aggregates were analyzed by XRPD, SEM-EDS and ICP-MS-LA also in order to evaluate the relationships between mineralogical composition and REE's content. Preliminary data indicate that phosphate-rich aggregates are mostly composed of hydroxilapatite, francolite and calcite.

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Braunite ($3Mn_2O_3 \cdot MnSiO_3$)-rich deposit within the ophiolitic sequence of southern Apennines, Italy

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Keywords: Braunite, metal and REE contents, Pollino massif.

Manganese is one of the tenth most abundant elements in the Earth's crust having concentrations commonly higher than 0.1% wt. in the average continental crust. As pure metal, manganese is widely used into the steel industry where it is added to iron and other metals (such as carbon, aluminium, silicon, nickel, chromium, vanadium) to produce special alloy steels. In natural environments the hydrothermal activity, continental weathering, and chemical precipitation in alkaline solutions are the main processes responsible for the manganese mobility. Differently to Mn oxides/hydroxides, the occurrence of Mn silicates as braunite (general formula $3Mn_2O_3 \cdot MnSiO_3$; Ostwald, 1982), is not very common because they mostly form in regionally metamorphosed manganese deposits or in hydrothermal veins. Numerous examples of braunite ores have been also documented within rocks and sediments of metamorphosed ophiolitic successions (Shah and Moon, 2007; Tumiati et al., 2010, and references therein). In this paper, we present the results of the mineralogical and geochemical study performed on fifteen samples of a braunite-rich deposit from southern Apennines (Italy), extensively exploited until the 70s and here described for the first time. The deposit is in proximity of the Monte Cerviero, at the Lucania-Calabria border, where the Mn silicates occur within the sedimentary rocks of the Lungro-Verbicaro Unit (Iannace et al., 2005). This unit consists of Triassic to Neogene carbonates that was part of the Adria continental paleomargin, locally cross-cutted by basic lava dykes. The X-ray powder diffraction analysis shows that variable amounts of braunite and quartz characterize the studied deposit. In some samples, also Mn oxides such as cryptomelane and/or hollandite, along with phyllosilicates and epidote (piemontite) have been detected. The ICP-MS analysis revealed that the studied braunite-rich deposit is a medium to high-grade ore having MnO contents higher than 30% wt. However the amounts of MnO strongly vary in the range from 33.8 to 71.7% wt. Similarly to MnO, the SiO_2 contents also show a wide range varying from 4.1 to 50.4% wt. The other major elements have very low concentrations, except for Fe_2O_3 and K_2O that achieve 6.4% wt. and 2.3% wt. respectively. It is worth noting that Ba, in addition to some transition metals including Co, Ni, Cu and Zn, may have concentrations higher than those of the Upper Continental Crust. The chondrite-normalised REE patterns show LREE/HREE fractionation (6.80÷23.90), negative Ce anomalies (0.09÷0.90) and Eu anomaly in the 0.67÷0.81 range. The REE patterns are thus similar to those observed in low-temperature hydrothermal deposits (Şaşmaz et al., 2014).

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Ore Characterization by the use of Automated Mineralogical Analyses using Mineralogic Mining (ZEISS) technology: results from Hakkari (Turkey)

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Keywords: Zinc nonsulphide, Mineralogic, Automated microscopy.

The Hakkari Zinc Project is a supergene nonsulfide Zn>>Pb deposit located in the Southeast of Turkey. Total resources estimated consist of 10 Mt @ 15% Zn. The ore concentrations mainly consist of oxidized Zn minerals (smithsonite and hemimorphite) derived from the weathering of sulphides, hosted in shallow water Jurassic limestone.

This preliminary study is focused on the mineralogical and petrographic characterization of 4 Hakkari samples in term of quantitative *modal mineralogy* and *average mineral association.* The 4 samples were taken from different oxidation zones representative of the deposit, in order to characterize and quantify all the occurring mineral phases. The analyses were carried out by the use of a new generation of Automated Mineralogical Analyses system known as "Mineralogic Mining" (ZEISS), which utilizes modern quantitative EDS technology to allow minerals to be classified based on the % element abundance (stoichiometry).

Previous QEMSCAN (FEI) analyses for the same 4 samples of the Hakkari mineralization (Santoro et al., 2014) provided a strong basis for the Mineralogic routine, and were used to assess the accuracy and the capabilities of Mineralogic system.

Mineralogic Mining was able to build high-resolution maps and to clearly identify and quantify the major economic phases such as smithsonite and hemimorphite (up to ~58 wt.% and ~67 wt.% respectively in the analysed samples), and gangue phases as goethite (up to 38 wt.%). Minor phases such as barite (up to ~6 wt.%), dolomite (up to ~7 wt.%) calcite (up to ~8 wt.%), cerussite (up to ~8 wt.%), gypsum (up to ~1 wt.%), traces of pyrite, chalcophanite, hetaerolite, quartz, coronadite (<0.50 wt.%) were also detected in the analysed samples. It was also possible to identify the "*impure*" metal-bearing minerals: mainly Zn-enriched goethite (up to ~54 wt.%), but also traces of Zn-dolomite, Fe-dolomite, Mg-smithsonite, and Fe-smithsonite (<1 wt.%). The technique was clearly able to distinguish between two very similar mineral phases (i.e. ankerite and Fe-dolomite).

The mineral association of the major mineral phases was also investigated. The results show that smithsonite and hemimorphite are generally associated together and with Zn-enriched goethite (in agreement with previous studies, Santoro et al., 2014).

The software was also able to automatically calculate the distribution % of Zn in the different mineral phases, information which can be critical during geometallurgical modelling, feasibility studies and process planning, as it can help to predict metal losses during the treatment. The results on the analysed samples show that Zn occurs mostly in smithsonite, hemimorphite (as predictable) and in goethite (Zn-enriched goethite).

This study revealed the effectiveness of the Mineralogic automated mineralogy system in ore characterisation, to be used during the feasibility studies in the exploration stage and processing modelling, as an early aid to the evaluation of possible recovery problems.

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Provenancing bronze, alabasters, and bones: exclusion, inclusion and Occam's razor

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Keywords: Archeometry, Bronze, Alabaster, Prehistory.

The task of identifying the provenance of archeological objects can be called "fingerprinting". One evidence currently used are chemical and isotopic compositions. In contrast to human fingerprints, which according to present forensic knowledge are unique, archeometric fingerprinting is not yet able to identify with certainty the source(s). Exclusion is more decisive than inclusion: according to archeometric arguments an artifact can be certainly incompatible with a number of sources, but can be possibly compatible with a number of others. By Occam's razor one can retain the hypothesis that makes the smallest number of unreasonable assumptions.

To reduce ambiguities it is possible to judiciously combine chemical and isotopic indicators. In the case of bronze artifacts, one option could seem to be supplementing the Pb isotopic composition with trace element concentrations. However, unsupervised software seldom provides correct identifications, as automatic statistical routines do not take into account geological and mineralogical facts. It is therefore necessary to select homogeneous element ratios, e.g. Sb/As, related to the genesis of the ore (it reflects the tetrahedrite/tennantite ratio), combined e.g. with the Ag/As ratio, which is sensitive to metallurgical roasting. Villa (2016) discusses the properties of additional geochemical discrimination plots to recognize mixtures (due to recycling of bronze artefacts, doping with additives to improve material quality, mixing heterogeneous ore batches, etc).

Alabasters have been often characterized by Sr isotope analyses. The difficulty lies in their genesis: carbonate alabasters, the most widespread Hellenistic and Roman variety, form from a comparatively uniform marble/carbonate source rock by patchy recrystallization following fluid infiltration, whereby the fluids carry the Sr isotope signature of the surrounding crust. Therefore, antique alabaster quarries around the Mediterranean have (i) strongly heterogeneous and (ii) mostly overlapping Sr isotopic signatures. Improvements are expected if the database will be augmented to include Pb isotope analyses associated with earth-alkali element ratios (Ba/Sr/Mg).

Teeth can reveal the provenance of an individual, as they are better preserved after burial (solid tooth apatite is more resistent to alteration than porous bones; moreover, it is not modified in vivo after infancy). It is challenging to assign a specific provenance to an archeological find, due to the very large number of areas whose combined protein sources (vegetables and animals) match a given Sr isotopic composition. A combination of Sr and Pb isotope ratio measurements can add clarity to the discrimination. This makes it easier to spot migrations, when tooth Sr and Pb isotope signatures in a cemetery change suddenly at some point in time.

Villa I.M., 2016. Chapter 8. In: Grupe G., McGlynn G.C., eds., Isotopic landscapes in Bioarcheology. Springer, ISBN 978-3-662-48338-1, 141-154.

Session S34

Cultural Heritage in marine and subaerial environment: knowledge, development, fruition and protection

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The evaluation of archaeological potential of the Benevento urban area (Southern Italy) inferred by geological and archeo-stratigraphical data

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Keywords: Geomorphology, Stratigraphy, Urban areas, Cultural Heritage, Predictive Archaeology.

Benevento is a town situated in the inner part of the southern Apennines and is mainly located on the top of a Pleistocene terrace and is almost entirely bordered by rivers. Dating from prehistoric times, Benevento has constantly been chosen as a favorable location for settlements. Starting from the Samnitic age, especially during the Roman and Longobard ages, was affected by several moments of urban transformations, at times, induced by destructive earthquakes and floods. A large part of the modern town was built on a thick archeological stratification, that contains the remains of the older towns. A geoarchaeologic study has been ongoing since 2011 by an interdisciplinary research group of specialists from various disciplines: archaeology, architecture, computing, geology and geomorphology. The study is a tool of the SiUrBe (Sistema Informativo del Patrimonio Archeologico Urbano di Benevento), a project partnership between the Benevento Office of the Superintendence of Archaelogy of Campania (Soprintendenza Archeologia della Campania), and the Department of Cultural Heritage Science of the University of Salerno (Dipartimento di Scienze del Patrimonio Culturale dell'Università di Salerno) (Santoriello et al., 2013; Amato et al., 2015). The goals of the project are the reconstruction of the ancient landscapes and environments since Early Holocene and the chronology and the causes of their changes, aimed also at evaluating the archaeological potential of the Benevento urban areas. Starting from the acquired geological, geomorphological, stratigraphical and palaeoenvironmental data and the archaeological background, selected in an appositely made GIS system, the main aim of this paper is to develop a map of the archaeological potential of the Benevento urban areas, in order to hypothesize the potential depth, under the current ground level, of the archaeological layers. The map could become a useful tool for public administrations and private citizens in the planning and budgeting of new renovation works or new buildings, and thus giving the possibility to transform what is today seen as a "risk" into "potential".

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The Roman *villa* of Positano (southern Italy): preliminary mineralogical study of various archaeological findings

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Keywords: Roman villa, Positano, Julio-Claudian age, pyroclasts, artifacts

At Positano, the renowned town of the Amalfi coast (Salerno province), a Roman *villa* was found beneath the church of Santa Maria Assunta. It likely dates back to I century BC - I century AD (Julio-Claudian age) and belonged to the freedman Posides Claudi Caesaris, from whose the town might probably derive the name (Della Corte, 1936). The *villae* were prestigious residences disseminated as status symbol of the wealthy Roman people all around the coastal areas of the Campania region (i.e. Vesuvian *villae*; Maiuri, 1955. Guzzo & Guidobaldi, 2008). During the 79 AD eruption of the Vesuvius the residence was suddenly destroyed and covered by a volcanoclastic debris flow more than 10 m thick, composed of a mass of gray ashes with large amount of high-porosity welded pumices. During the Middle age, Benedictine monks built an abbey on the same site of the Posides' *villa*, then transformed in the present church dedicate to the Virgin. At the beginning of the 2000, the Archaeological Superintendence started the recovery of the overlying Benedictine crypts and extended the excavation and recovery also downward to the *villa* remains. Inside the crypts it was possible to unearth, descending in the *villa* from tiles roof till to mosaic pavement, a luxurious *triclinio*. Imprints of holes related to large wood poles (now replaced with plaster casts), as well as fragments of the roof, coffered ceiling, doors and other wooden remains were found embedded in the volcanoclastic mud. Tuff walls are decorated with fine plasters, polychrome frescoes of excellent painters, with hippocampus, eagle poised upon a globe, Pegasus and Cupids. These lively compositions are basically made by some colors, like the "Pompeian" red, blue and yellow ochre. This work reports a preliminary archaeometric study of various artifacts from the Positano *villa*, represented by plasters, fresco fragments, tile and other materials. Small but representative samples of the different findings were analyzed, in order to reach our characterization scopes and to provide useful information on probable future restoration activities. The analytical techniques used for mineralogical and petrographic study are: optical and stereoscopic studies on thin sections, modal analysis, X-ray powder diffraction (XRPD), scanning electron microscopy analysis (SEM) and energy-dispersion X-ray spectroscopy (EDS). Data concerning the composition of the artifacts and manufacturing techniques will be reported and compared with the reference literature.

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The use of Laser Ablation ICP-MS in Cultural Heritage studies

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Keywords: LA-ICP-MS, trace elements, archaeological finds, black crusts.

In recent years, growing attention has been paid at the use of various instrumental analytical techniques to characterize the raw materials employed in the production of objects, monuments and buildings of historical-artistic interest. The Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) method has become available in the mid-1990s. It uses a laser beam that ablates a small portion of solid sample, fluxed into the plasma stream by a carrier gas. This analytical method, almost non-destructive, allows to analyse "in situ", with spot analyses from 50 – 100 micron, trace elements in a very short time, without any sample manipulation. For these peculiarities, the LA-ICP-MS, has become widely used for the chemical characterization of archaeological finds.

A series of examples of application of LA-ICP-MS in cultural heritage will be presented, both in archaeometric and degradation studies.

In particular, very interesting results have been obtained in the provenance study of the raw materials employed in the mixture to produce the plasters collected in Teotihuacan - Mexico (one of the most important cities of the Mesoamerican Classic period).

In the study of degradation processes, the application of LA-ICP-MS to the study of black crusts on buildings and monuments, allowed to evaluate the degree of atmospheric pollution through the determination of the concentration of trace elements, especially heavy metals.

A geological, archaeological and anthropological journey throughout the north-eastern Basilicata, Italy

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Keywords: Geoturism, itinerary, Southern Apennines.

The proposed geological, archaeological and anthropological journey takes place along the north-western sector of Basilicata, which exposes a high geodiversity and a great variety of landscapes. Following a multidisciplinary approach, the peculiarities of each stop are reported in the following text.

Stop 1- Hypogea of the Pietragalla village. The village of Pietragalla is built largely in Numidian Flysch made up of quartz sandstones of Aquitanian-Langhian age. The quartz sandstones were dug to carry the millstones and cellar, used for the grape processing and wine storing, respectively. These hypogea contain from one to four fermentation tanks, such as those commonly used by one or more families, and consist of a small gate, a tank used for grapes pressing, and by a large bowl used for must fermentation.

Stop 2 - The San Fele waterfalls are located along the Bradano creek, a tributary of the Fiumara di Atella characterized by several morphological cliffs exposing the Upper Triassic Calcare con Selce Fm. pertaining to the Lagonegro succession, which give rise to natural and suggestive waterfalls.

Stop 3 - Paleolithic archaeological area of Atella. The site was discovered in 1989. There, fossils of elephants, primeval oxes, bisons and deers are present. The soil stratigraphy is consistent with multiple changes of the lake water level caused by the eruptive activity of Vulture Volcano, the sensitive period climate change, the mechanical disturbances and landslides, probably relating to human activities.

Stop 4 - Monticchio's lakes. The small, circular lakes are located within the caldera of the Vulture Volcano, along the south-western side of the edifice. The two lakes show steep and symmetrical flanks, remarking their colonic origin (maar).

Stop 5 - Haüyna deposit of Melfi. The site is located next to the castle of Melfi, and it is characterized by presence of large Hauyna crystals and clinopyroxene embedded in a microcrystalline matrix of nepheline, leucite, magnetite, sodalite, Na-ferrimelilite and apatite. The melilite present within the Haüyna deposit is the only iper-alcaline rock of the Vulture area, and the richest Na-iron component melilite ever found in Italy.

Stop 6 - Jewish Catacombs of Venosa. The Jewish Catacombs, dug during the V-VII centuries D.C., are located along the southern sector of the Maddalena hill. In fluvial-lacustrine basin of Fiumara di Venosa-Mattinelle several phases of sedimentation occurred, which are influenced by the activity of the Vulture volcano that caused the silting of the lake basin. These deposits (middle Pleistocene) characterized by two lithostratigraphic units that are gravels and tuffites and tuffites and silts with travertine and gravels.

Stop 7- Notarchirico is an archaeological site, located in the vicinity of the Venosa town, in which elephant skulls with two tusks and jaws of Lower Paleolithic age (about 359 Ka) were found. Moreover, the site exposes remains of *Palaeoloxodon antiquus*, Bovidae, deers, rhinoceroses, hares, turtles and birds are also present. A femur of *Homo Erectus* is also present.

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The Argentario coast towers: geomaterials, history and conservation state

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Keywords: Argentario, geomaterials, history, state of conservation.

Known by the Etruscans for its safe docks in their maritime trade, the Argentario peninsula was inhabited by the Romans, as evidenced by the ruins of Cosa (273 BC) on the hill of Ansedonia, and by the luxurious residence of the Domitii Enobarbi family, "argentarii as profession", i.e. bankers, in Santa Liberata.

After the fall of Roman Empire, the Argentario history became confused with that of the surrounding areas, controlled by Barbarians, Byzantines, Lombards until the coming of Carlo Magno.

Later on Argentario became, during the XII century, property of the Aldobrandeschi family, important noble family whose domains centered on Colle di Val d' Elsa, Fiora and Sovana.

In 1414, Argentario passed with Orbetello and other territories under the control of the Republic of Siena. In the Senese period, the first systematic fortification of the peninsula, against the barbarian invasions that became more frequent and devastating, was realized.

In 1557, following a military defeat, all the Senese territories passed in 1557 under the rule of Cosimo I de' Medici and Philip II of Spain reserved for himself a small coastal strip comprising Orbetello, Talamone, Argentario, Capalbio and subsequently part of the Elba island, that formed the State of Presidi. Philip II increased the military connotation of the territory upgrading the network of existing coastal towers and with the constructions of numerous and mighty fortresses: from 1563 to 1571, under the impulse of the Spanish viceroy of Naples Pedro Afan de Ribera, 17 coastal towers were realized in the territories of Orbetello and Argentario. The Spanish rule ended in 1707, leaving a deep urban and architectural traces.

In this contribution, within an historical and architectonic context, the study of the geomaterials and state of conservation of three selected towers is presented. Stones ashlars and raw materials used for the preparation of bedding mortars were investigated with mineralogical and petrographic methodologies (optical and electronic microscope, X-ray diffraction) in order to enlighten the relationship with local geological outcrops.

Furthermore, a survey about the restoration interventions was performed in order to verify the compatibility of used materials and their durability.

Impact of a Changing Environment on Panamanian UNESCO sites for a Sustainable Culture

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Keywords: material characterization, cultural heritage, climate change, damage functions.

Panama, the narrowest strip of land of Central America, hosts two sites inscribed on the World Heritage List: the Archaeological site of Panama Viejo (XVI cent.) and the Fortresses of Portobelo and San Lorenzo (XVII-XVIII cent.).

In order to support the conservation and valorisation of these places, in 2014 a collaboration work was started between the Patronage of Panama Viejo, the Patronage of Portobelo and San Lorenzo, the Institute of Atmospheric Sciences and Climate of the Italian National Research Council (ISAC-CNR) and the Department of Earth Sciences of the University of Ferrara.

As a first step, the study was devoted to the characterization and the evaluation of the state of conservation of the building materials, obtained by mineralogical-petrographic, physical and chemical analyses (PLM, XRD, SEM-EDX, XRF, MIP and IC). Successively, in order to determine the environmental context, a selection of monitoring stations, near the sites of interest, recording climate parameters (near-surface air temperature, relative humidity and rainfall amount), have been selected among the network of the Authority Panama Canal. Moreover, the same parameters were collected from ARPEGE climate models (Déqué, 2010), both historical and scenario simulations, in order to utilize them for future damage predictions. Indeed, utilizing environmental data and applying specific damage functions it is possible to assess the deterioration phenomena occurring on heritage materials, for instance surface recession, biomass accumulation and transition of salts (respectively Bonazza et al., 2009; Gómez-Bolea et al., 2012; Grossi et al., 2011), as demonstrated within the 6 FP EC Noah's Ark Project (Sabbioni et al., 2012).

Therefore, this research work has allowed us to produce projections of possible climate change impacts on the Panamanian heritage, for the near to the far future (2011-2100), compared to the recent past (1985-2010).

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Geotourism and professional updating: the experience in Campania (southern Italy)

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Keywords: Geotourism, southern Italy, geological heritage.

During the last six years the "Order of Geologists" of the Campania region has promoted several geological field trips for the professional updating. These events of geotourism, organized in the whole region, involved hundreds of people, documenting in this way the preference of outdoors learning.

These actions also involve walkers and excursionists in general, in order to promote, enhance and raise awareness of the diversified geological heritage of the Campania area.

The locations of the excursions were chosen through a rational selection of sites (and geosites) where the geological heritage of the territory is mixed with natural and anthropogenic elements of considerable interest (Amato et al., 2010; 2011; Ciarcia et al., 2012).

Some of the visited locations in recent years are:

- Matese Mts: the Torano and Maretto springs and the alluvial fans;
- Agro sarnese-nocerino: the Sarno landslides and the Lithiotis limestones;
- Sorrento peninsula: the "Sentiero degli Dei";
- Cilento Geopark: M. Bulgheria and the Centola conglomerates;
- Vesuvius National Park: the volcanic cone and the Herculaneum excavations;
- Alburni Mts: the karst landscape and the footpath network;
- Campi Flegrei area: the Solfatare of Pozzuoli, the Averno Lake and the Monte Nuovo volcano;
- Vallo di Diano trough: the Pertosa caves and the Monti della Maddalena oil exploration;
- Roccamonfina volcano area: the "Ciampate del diavolo", made by Pleistocene hominids, and the Mondragone Marbles;
- Laceno upland: the paths of the Mesozoic rocks, the Caliendo cave and the Cassano Irpino springs;
- Caserta Royal Palace: the ornamental stones and their quarries provenance; the sources and the path followed by the waters of the gardens.

Most of these places were chosen because they represent institutional wilderness areas or national and regional parks, but other areas were privileged simply to promote them.

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The geological heritage: examples from south Italy inland areas

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Keywords: geological heritage, southern Italy.

The inland areas of southern Italy are often places of great geological interest and of great landscape beauty, but little known to the general public and, sometimes, even local communities are poorly aware of their importance. These are places where the geological structures appear in excellent exposure or are explanatory of the processes that generated them or, even, are particularly rich and significant fossil outcrops, so these areas are worthy of being protected and preserved. Some of the most appealing sites of geological interest, located in inland areas of South Italy (Sannio and Irpinia zones) are:

- Vitulano: some mines of Cretaceous polychrome marble, an ornamental stone consisting of reworked bauxites, calcareous breccias and reddish limestones, deposited in underground cavities;
- Cerreto Sannita: one of the best Italian pottery centre where the first potteries were founded in 1688; in the surroundings there are the grooves of the Titerno River carved in the Lower Cretaceous limestone to form the "Marmitte dei Giganti";
- Pietraroja: place of occurrence of a Cretaceous theropod dinosaur, named Ciro, characterized by an extraordinary soft-tissue preservation and of thin and very delicate abdominal bones;
- Montecalvo Irpino: numerous cold water bubbling mud volcanoes, named Bolle della Malvizza, with methane gas seepage close to Pliocene fossil beaches;
- Gesualdo: a material, commercially known as Onyx, is the like-quince alabaster (or calcium alabaster), formed by calcium carbonate accretions as result of cave environment;
- Rocca S. Felice: mentioned in classical literature (Aeneide, Virgilio), Mefite d'Ansanto bubbling spring, is a non-volcanic natural emission of low temperature CO2, enriched by Hydrogen sulfide and Methane gases.

It is therefore necessary to develop in the local communities the awareness that the protection and the valorization of geological and natural heritage is an opportunity of conservation and improvement of the existing natural levels in its own territory as well as an opportunity of economic development. Understand the "meaning" of the outcropping rocks and decode the processes that led to the formation of the landscape lead to an awareness of the fact that the Earth, as we see it today, is not an immutable object, but rather is the result of long processes , exogenous and endogenous, that have developed and developed over time. To achieve this we need a widespread diffusion of the territory knowledge and education to the environment. The knowledge of our own territory is the first step to properly manage and make accessible and understandable "the inanimate portion" of the territory. A proper policy of planning and land protection requires the integration of scientific knowledge, administrative skills, and agreement and participation of the populations involved.

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Raw materials for archaeological pottery: a multi-analytical approach

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Keywords: Archaeological pottery, archaeometry, raw materials, provenance, Bay of Naples.

Archaeometric analyses performed via minero-petrographic techniques provide useful information on technology and provenance of ancient pottery. Very helpful is also the availability of production indicators, such as kiln wastes, remains of raw material and unfired vessels, etc. In these years the synergistic approach between geologist and archaeologists allowed us addressing the production technology and circulation of pottery from various sites in the Bay of Naples area. A large number of pottery and other materials dated since archaic to medieval times was studied from the sites of Miseno, Cuma, Neapolis, Pompeii and other peri-vesuvian settlements, such as Pollena Trocchia and Stabiae.

An extensive programme of survey and analyses has been performed in order to identify the potential sources of clays used as raw materials in antiquity and compare their composition with that of the archaeological samples (De Bonis et al., 2013). Experimental firing of the most representative local raw materials was made in order to reproduce the ancient technological process by simulating firing dynamics and mix design (De Bonis et al., 2014). This was based on the information acquired from archaeometric analyses of pottery with different ceramic and functions, as well as from the direct knowledge of traditional potters.

A pioneering analytical approach is in progress to investigate pottery and raw materials. The comparing analyses of micro- and nano- fossils in both clays and pottery constrained the procurement area of raw materials, in particular for Pompeian productions. Isotope analyses applied for the first time on experimental samples show that the Sr-Nd-isotopic signature of ceramic is preserved even after artificial manipulation and firing of raw materials, thus representing a valid tool for provenance studies. Isotope analyses of archaeological pottery from the Bay of Naples allowed us to better discriminate among different productions and find a relationship with geological sources of raw materials.

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Unglazed Pottery from the *masjed-i jom'e* of Isfahan (Iran): Technology and Provenance

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Keywords: mineralogical-petrographic analysis, pottery.

The *masjed-i jom'e* (Friday Mosque) of Isfahan represents one of the earliest mosques of Iran. Since 1970 the Italian activities of IsMEO, now Università degli Studi di Napoli "L'Orientale", the Università degli Studi di Roma "La Sapienza", and Ministero Italiano degli Affari Esteri, contributed at identifying the earliest building phases of the monument, starting a conservation and archaeological project. An extensive investigation was carried out in order to complete the historical, archaeological knowledge of the monument. Since 2003 a new project: ADAMJI (A.rchaeological D.igital A.rchive of the m.asjed-e j.om'e of I.sfahan), started to resume a digital catalogue of the archaeological data.

Aim of this study is the investigation of technological features and provenance of the unglazed pottery from the mosque, via minero-petrographic approach. Pottery was selected among a huge amount of samples based on the recurrence of typologically identifiable fragments and fabrics (Genito et al., 2014; Massa, 2014). 23 pottery samples (storage, table and cooking wares) were investigated, along with two bricks, seven production indicators (spacers, kiln furniture, slags) and a local clay analysed for comparison.

Production indicators and most pottery are characterised by high-CaO concentration. Thick-walled wares contain coarse sedimentary/metamorphic inclusions. Other samples, characterised by thinner walls, show a similar petrographic composition, but contain fine/well-sorted grains. Mineralogy and microstructure indicate firing temperatures mainly ranging from 850 to 1000 °C. Low-CaO samples contain sedimentary inclusions; in one samples volcanic lithics are present. Firing was made from about 800 to 950 °C and the low-CaO character could be related to their specific function for cooking foods. One sample, found in older stratigraphic levels, differs for its peculiar calcitic temper and lower firing temperature.

Local provenance was constrained for most samples due to the composition of the inclusions compatible with the sediments of the Isfahan area. High-CaO pottery shows compositional affinity with production indicators, a local clay and tiles produced in Isfahan in the Safavid period. Cooking ware contains local temper, except for a sample with volcanic inclusions that could have an exotic provenance. Regarding the used clays, currently we have no appropriate information about availability of low CaO clays in the area.

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Multi-analytical approach for the study of mortars and plasters from the *Forum* of *Pollentia* (Mallorca - Spain)

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Keywords: Pollentia, Balearic Islands, mortars, plasters, Roman production technology, constructive phase.

This paper shows the result of a multi-analytical approach used for the study of mortars and plasters coming from the *Forum* of *Pollentia*, an ancient Roman and Late Antique city located in the north-eastern coast of Mallorca (Balearic Islands, Spain). In this work, that comes after a first publication (De Luca et al., 2013), a total of 27 samples of mortars and plasters coming from different buildings of the *Forum* were analysed. The materials under study were selected from the so-called *Insula of tabernae*, the Temple I, the Temple II, the East Building (probably identified as a *Basilica*) and the *macellum* (market) at the East side of the *Forum* (Orfila et al., 1999; Cau & Chávez, 2003; Chávez et al., 2010).

The petrographic, mineralogical and chemical characterization of the samples was carried out through Optical Microscopy (OM), X-ray Powder Diffraction (XRPD), X-ray Fluorescence (XRF), Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) and Image Analysis by the "JMicro Vision" software. The geochemical data were also subjected to multivariate Cluster Analysis.

The results obtained allowed to determine the raw materials used for the production of mortars and plasters. The samples show mainly two different typologies of aggregate that represent two clear different sources of raw materials, compatible with the geology of the source area. Samples study had also provided useful information about the building techniques, the production technology of mortars and plasters and the constructive history of the studied buildings (Miriello et al., 2011; De Luca et al., 2015). Indeed, through this study it was possible to identify different groups of samples that were attributed to different constructive phases, according to the archaeological results.

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The palaeoenvironmental history of the *Neapolis* (Naples, Italy) harbor basin from the Augustan Age up to the Late Antique period

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Keywords: geostatistics, mollusks, granulometry, lagoon.

In the last 20 years, archaeological excavations undertaken during the construction of the new Naples subway have unearthed the harbor basin of the Graeco-Roman town of *Parthenope*-*Neapolis*. The opening of a new archaeological dig (Line 6) in 2012 offered the opportunity to improve the previous knowledge about the basin evolution, due to the recovery of huge amounts of archaeological remains as well as of a thick succession of infilling sediments. The latter have been analyzed by means of sedimentological and paleontological analyses whose results have been treated through Compositional Data Analysis (CoDA). This approach has highlighted the palaeoenvironmental changes along the harbor basin infilling, from the Augustan Age up to the Late Antique period. The first infilling phase occurred in a marine infralittoral environment which evolved into a lagoon environment at the beginning of the 5th century AD. This change precedes the final closure of the bay at the end of the 5th century AD, due to increased alluvial inputs from inland, probably connected to both natural and anthropogenic causes.

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Understanding rock materials exploitation along the Ancient Aappia route by means of integrated geoarchaeological and microstratigraphic analyses

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Keywords: Geoarchaeology, rock caves, optic microscopy, stratigraphy, Via Appia, Italy.

A comparison between Mesozoic carbonates and ancient Roman ashlars was performed by microstratigraphic analyses to complete a geoarcheological characterization of a rock cave system featuring the Ancient Appia route where it crosses the Aurunci ridge along the San Andrea Valley, between the modern villages of Fondi and Itri (southern Latium).

This research is part of a FIRB project led by the CNR-ITABC in collaboration with the Second University of Naples - Department of Literature and Cultural Heritage, to which other Universities, CNR Research Institutes and private societies have occasionally collaborated.

The understanding of the anthropogenic landscape modifications required a multidisciplinary approach. Rock caves carved into the southern edge of the valley were acknowledged by previous studies (Quilici, 2003; 2011) and has been better defined in this work in terms of cave dimension, volume of exploited materials, and extractable block modules. Extracted stony material was used for the original road pavement (IV-III cen. BC) and to raise outstanding, polygonal-worked retaining walls sustaining the route terrace.

From a geological standpoint, a shallow-water carbonate sequence, pertaining to the Apenninic Carbonate Platform palaeogeographic domain, crop out in the study area (Centamore et al., 20007). To check the compatibility between outcropping limestone within caves and Roman building material, 38 samples were collected, and their textural and palaeontological features analysed by optic microscopy. The analyzed lithotypes belong to a Cretaceous inner-shelf environment and are mainly composed by micritic limestones with benthic foraminifers and dasycladales algae. These are locally interlayered with packstone and grainstones, dolomitized limestones, grey-greenish marly clays and reddish limestone strata.

Rock samples were grouped on the basis of similar textural characters. Six different lithotypes were recognized and, when possible, dated on the basis of their micropalaeontological content. Results show the preferential use of coarse-grained Aptian limestones on the northern part of the road tract and Cenomanian-Turonian limestones in correspondence of the southern zone.

Both the morphometric characterization of rock caves and the correspondence analysis between source areas and Roman masonries revealed an original geo-engineering planning for a systematic and functional exploitation of the local environmental resources.

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Chemical-petrographic and isotopic provenance analysis of the volcanic rock pavement along the "Via Appia" between Fondi and Itri; insights for possible geoarchaeological scenarios

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Keywords: Geoarchaeology, provenance analysis, Via Appia, Italy.

The "Via Appia" was built since 312 BC and its extension brought the road track from Rome to Brindisium (modern Brindisi) by 264 BC. On the Tyrrhenian side, the "Via Appia" runs between the Colli Albani Volcanic District and the Tyrrhenian coastline. Southeastward, it enters the Fondi Plain and then climbs over the Aurunci mountains (e.g. Quilici, 2011). Before arriving in the Capua Plain the road crosses the Roccamonfina volcano.

We present new analyses aimed at unravel the provenance of the volcanic rock pavement from the road track between Fondi and Itri, which was added under Emperor Caracalla (211-217 AD). This study was led in the frame of a FIRB project coordinated by CNR-ITABC in collaboration with the Second University of Naples - Department of Literature and Cultural Heritage. To achieve such a goal other CNR institutes, i.e the IGAG and IMC, and the INGV-OV were involved. The general aim of the project is the knowledge of an area of high archaeological and landscaping value for its promotion and valorization.

Thin sections of five samples from the rock pavement were analyzed by an Electron Microscope Probe. Samples consist of grey, non vesicular, moderately porphyritic lava stones. Chemical-petrographic characterization of mineral phases outlined the typical paragenesis of high-K series, with dominant leucite and clinopyroxene. Plagioclase (labradorite) and apatite are also frequent, along with rare Fe,Ti-oxides, olivine and amphibole as microphenocrysts, with a groundmass microcrystalline to hypocrystalline. Petrographycally, these rock types are phonotephrites.

87Sr/86Sr isotope ratios measured on four bulk rocks are in the ~0.71018 to ~0.71019 range, while the fifth sample has a 87Sr/86Sr ratio of ~0.70946. 143Nd/144Nd isotope ratios are inversely correlated to Sr isotopes. Isotopic compositions are within the range of high-K rocks of the Roman Province. Lava samples match the isotopic, geochemical and mineralogical features of the Roccamonfina, pre-caldera effusive phase of activity (630-385 ka), thus excluding a provenance from the Colli Albani, Somma-Vesuvius, Phlegraen Fields and Pontinian Islands volcanic areas. Studies on ancient rock caves in the Roccamonfina territory (Panarello, 2008) support our hypothesis, although the eastern edge of the Aurunci mountains seems a serious natural barrier for material transportation. Alternatively, the chemical composition of products from the Mts. Ernici high-K effusive phase of activity also fits our analytical data, thus depicting intriguing geoarchaelogical scenarios involving commercial relationships between the Latina Valley and the peri-Tyrrhenian territories.

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Pompeii geoarchaeological setting – An archive older than 40,000 years of volcanism, soil formation and geoarchaeological landscape

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Keywords: Pompeii, archaeological heritage, geoarchaeological investigations, boreholes, lithostratigraphy.

The present work describes the results of full lithostratigraphic, pedological and geoarchaeological studies carried out in the Pompeii archaeological area (southern Italy), combined with logs data, surface and underground survey of lava and tephra outcrops. The ancient Pompeii is probably the most famous and complex site of archaeological investigation in the world. Through many studies have been devoted to various archaeological aspects, detailed reconstructions of the geological setting and history of geoarchaeological landscapes are still lacking. At present, Pompeii landscape consists of low hills recognized as volcanic landforms and attributed to the Somma-Vesuvius volcano activity; they correspond to ancient local vents covered of a multilayered succession of repeated volcanic deposits and paleosoils, mainly related to alternating volcanic activity and quiescence periods with consequent pedogenesis (De Maio and Stefani, 2004; D'Ambrosio et al., 2001; Cinque and Irollo, 2004). This succession comprises at least the last 40,000 years of sedimentation history, reflecting the entire spectrum of eruption types of the Somma-Vesuvius, i.e. from Plinian to sub-Plinian eruptions, relatively small eruptions to effusive volcanic events and, on the other hand, soil formations of different durations, intensities and soil-forming environments. Before the foundation of the city, paleosoils repeatedly reveal clear evidence of anthropogenic activity, represented by agricultural practices. Once the city has taken to develop, anthropogenic landscape changes become particularly pronounced. The various periods of edification of the city walls required different types of land management, related to the variable morphological profiles encountered along of defensive wall circuit (longer than 3 km). Outcrops were deeply modified with quarries, underground excavations, earthworks. Several wells were drilled deeper than 20 meters to reach the water table. Two main geological sections, carried out through the Tempio di Venere and the Regio VIII Insula southern lava cliff, show a core of lavas locally capping buried deposits of the Campanian Ignimbrite. Geological risk assessment in such a complex archaeological site needs specific evaluations/methods and flexibility, according to specific conditions and case studies.

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Salerno geoarchaeological landscape recontructions – Urban geoarchaeology

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Keywords: Salernum, coastal floodplain, urban geoarchaeology, boreholes GIS.

The narrow coastal plain of Salerno, located at the base of steep carbonate slopes which face the Tyrrhenian Sea, has undergone major landscape changes over the last 2000 years. The coastline of the Salernum (the ancient Roman town) area has shifted southwest, with a partially defined scenario related to its palaeoenvironmental reconstruction. The location of the main water basin that hosted harbour structures, as well as traces of the port, is still not well defined. Recently, there has been progress in the palaeoenvironmental reconstruction of the coastline thanks to the collection, revision and analysis of old and recent logs (Di Maio et al., 1998, 2003). Data was combined with the interpretation of geoarchaeological sections and archaeological findings, suitable as markers for ancient sea-level recognition. The new subsurface data presented here, together with the analysis of unpublished archaeological data, give evidence of the ancient city topography.

The main environmental changes in the area have been detected: a few centuries before the colony was founded, the coastal plain had been characterized by a complex network of wetlands, swamps and marshes limited by dune ridges and fluvial sand bars. The spatial relationship between coastline, river/channel network, debris flows, lobes on coastal fan surface, etc. were not fixed.

Particular attention was paid to the reconstruction of the pre-79 A.D. vesuvian eruption coastal landscape. Salernum was affected by an important landscape modification related inter alia to the huge amount of tephra that fell into the sea. Strong changes were imposed by the tephra even to river networks, agricultural irrigation canals and ancient power channels of mills. Estuarine adjustment is supposed to have occurred for the Picentino River mouth and consequently for the ancient port therein hypothesized. In determining the precise position of the Roman coastline it is useful to constrain the area in which archaeological surveys should be concentrated, in order to identify the harbour location. Moreover, some of these results have been used to infer altitude constraints on the sea-level position in Roman times; preliminary data pointing to the construction a Late Holocene local sea-level curve in the area is presented, whereas the organization of a preliminary GIS of logs is ongoing.

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Matera (Italy), the European capital of culture 2019: lithoids, resources and cave dwellings

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Keywords: Calcarenite di Gravina, Matera (southern Italy), petrographical and mineralogical characterization.

Matera, a town of southern Italy, has a very ancient settlement history dating back to the Paleolithic age. Since 1993 the Archaeological, Historical, and Natural Park of the Matera Rupestrian Churches, and the so-called "Sassi di Matera" have been included in the UNESCO's World Heritage List. The strong archaeological and historical value of the urban area shows a continuity of very peculiar settlement patterns, from ancient time to the Middle Ages and beyond. The Matera's rock dwellings consists of habitations and work sites carved into the karstified and poorly cemented calcarenites belonging to the middle Pliocene-lower Pleistocene "Calcarenite di Gravina Formation". This formation largely crops out in the Murge area (Apulia, SE-Italy) where it unconformably overlie the Cretaceous rocks of the Apulian Carbonate Platform. Due to its nature, the calcarenite (porous carbonate rock) can be subject to much kind of chemical, physical and biological alteration that lead to severe decay effects of monuments. Several type of degradation, such as chromatic alteration, alveolarization, exfoliation and detachment, characterize most of the Matera's Rupestrian Churches. In order to understand the main degrading causes and to individuate the actions suitable for the preservation of such a historical heritage, a detailed study of the building rock is needed. With this in mind, the present work focused on the petrographical and mineralogical characterization of the Calcarenite di Gravina with the aim to define both its textural properties and mineralogical composition. The analysed rocks were collected along the left side of the Torrente Gravina ravine that border the Matera town at east. The preliminary results of our study show that, the examined calcarenites can be classified as fine- to coarse-grained grainstones and medium-grained packstones. The general fabric is one of loose packing calcarenite, poorly to moderately sorted with both a self-supporting framework of skeletal grains of marine organisms, and sub-rounded and rarely sub-angular terrigenous clast fragments. Some differences between grainstone and packstone can be highilighted. Grainstone is characterized by isotropic recrystallization of the calcite form isopachous crusts, common in inter- and intra-particle pores. In this rock, the matrix is almost completely absent. The size of lithoclasts ranges between 96-864 μm and that of skeletal components is between 240-768 μm. The porosity is mainly due to the patch of interparticle and intraparticle and some vuggy. Conversely, packstone has low contents of micritic matrix that somewhere shows evidences of partial recrystallization. In this calcarenite the porosity is mainly made up of vuggy and moldic often associated to the presence of skeletal components. The latters have dimensions ranging from 125-570 μm. In both calcarenites, scheletal consists of benthonic foraminifera, bryozoa, lamellibranchs, gastropods, echinoderms and red calcareous algae.

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The archaeological site of Kaulonia (Calabria, southern Italy): new insights from drone surveying and sediment provenance

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Keywords: Kaulonia, Magna-Graecia, archaeology, geology.

In recent years the site of Kaulonia, a small coastal Magna-Graecia settlement permanently occupied from the beginning of the seventh century B.C. to the Late Antiquity and beyond, has often been in the spotlight of both the scientific world and the national press. This is due, on one hand, to the important discoveries occurred over the years (among them the mosaic present inside the complex of the Hellenistic thermal baths, unique in size in Southern Italy, and the inscription Tabula Cauloniensis, the longest document in Achaean alphabet ever found in Magna Graecia), on the other, to the partial loss of archaeological vestiges due to a rapid coastal erosion affecting the terraced deposit where these archaeological remains are positioned. The geological studies have broadly traced the history of ancient Kaulonia since the mid-Holocene to present (Lena & Iannelli, 1996; Stanley et al., 2007); the results indicate that the coastline at this site experienced a relatively complex pattern of back-and-forth shoreline migration, as a result of combined sea-level rise, tectonic uplift and subsidence effects, with ultimate submergence taking place at some time after departure of the Greeks. The archaeological studies have delineated a more detailed history of the occupation time, providing suggestions, for example, on how and why the site was abandoned. At present, the exposure of an extensive outcrop (up to 8.4 m high and 380 m long) of the terraced deposits, due to coastal erosion, has enhanced our knowledge on Kaulonia history. Before the emplacement of coastal protections along the recently exposed cliff, new data have been collected. A high resolution (cm) drone surveying was carried out on the entire archaeological site with a twofold purpose: to document and store important stratigraphic and geoarchaeological information, otherwise forever lost, and to provide a good cartographic basis for editing of geo-referenced maps, like those recently implemented by the Soprintendenza Archeologica of Calabria for research, protection and enhancement of the site. Sediment samples have been collected from the main stratigraphic units identified on the cliff, particularly from those characterized by evidence of human settlement. Sediment composition and texture analyses have helped in defining the natural controls that induced to the abandonment of the site.

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Micro-Raman spectroscopy in the definition of provenance and technological characterisation of pottery: the study of Campanian Late Roman productions by means of a pseudo-correlative approach

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Keywords: Micro-Raman spectroscopy, archaeometry, pottery, Campanian Late Roman.

During the last decades, the application of μ-Raman spectroscopy in the archaeometric fields significantly increased, making it the elective vibrational technique in the study of archaeological artefacts since its non-destructiveness, non-invasiveness high sensitivity and high spectral resolution. Particularly suitable for the identification of μ-sized mixtures components, μ-Raman spectroscopy is ongoing in the archaeometric characterisation of the ceramic materials, constituting a more rapid and cheaper alternative than the "customary" techniques.

Providing satisfying information on the mineralogical assemblages of ceramic pastes, the characterisation by means of the μ-Raman spectroscopy can provide useful archaeological issues concerning the provenance of raw materials and the technological processes adopted in the past.

The present research is focused on the application of μ-Raman spectroscopy to pottery shards from three representative archaeological sites of Campania region, in order to infer the provenance key-elements and technological markers also by comparison with data from "canonical" analytical techniques (SEM/EDS, XRD and Mössbauer spectroscopy).

The chemical and mineralogical composition of temper grains by the combined use of μ-Raman spectroscopy and quantitative EDS was used to find typical elements for provenance.

In the pottery from Campania region one of the most important element to infer the provenance is the volcanic temper. The chemical composition of volcanic temper enclosed in the analysed pottery produced from peri-volcanic areas of the Bay of Naples reflected the volcanic affinity of the two main volcanoes, namely strongly alkaline for the Somma-Vesuvius and alkaline for Phlegraean Fields. The pottery production of the Apennine inland, also accounting for the presence of volcanic temper from Somma-Vesuvius fall deposits, can be distinguished by the frequent occurrence of siliciclastic grains.

The μ-Raman measurements well fit the results from EDS data since the Raman spectra of the mineralogical phases (e.g. feldspar, clinopyroxene, amphibole, garnet) are consistent with the mineral chemistry obtained by quantitative EDS. Actually, the μ-Raman measurements provided the same mineralogical and chemical results thus avoiding additional sample preparation (only the thin section is required) and precise calibration.

As far as the technology is concerned, μ-Raman analyses performed on the ceramic matrices allowed investigating the firing conditions experienced by ceramic samples. The collected data confirmed that variable temperatures and atmosphere occurred during the firing. In fact, the zoned pastes, which showed the Fe-oxides in both oxidation states (hematite and magnetite), accounted for a low accuracy in the ceramic production. The same result was previously accomplished by combining XRD and Mössbauer spectroscopy with all the careful analytical procedure and sample preparation required.

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Geomaterials in roman age: the case study of A41 mausoleum from archeological site of "Porta Mediana" Necropolis, Cuma (Italy)

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Keywords: Geomaterials, Archeology, Cuma Necropolis, Heritage protection.

Geomaterials from Campanian Region (volcanic and sedimentary materials) have been widely used since ancient times in the local architecture both for their high availability in the area and for their good petrophysical features. An outstanding example is the archeological site of "*Porta Mediana*" Necropolis of Cuma, known since the 17th century and revealed by the Centre Jean Berard archaeologists, between 2001 and present. The researches, within the 'Kyme 3' project, revealed about 70 mausoleum belonging in a time range from 4th century B.C. and 6th century A.D., with different building phases (Brun & Munzi, 2010). Among the monuments, the mausoleum named as A41 (early 3rd century A. D.), located at the crossroad between the Via Domitiana and the road axis to Capua, is particularly interesting due to the presence of many graves with well-preserved paintings. The funeral building is a cell grave with rectangular shaped base, and was built on a previous edifice (approx. 1st century A.D.); external walls are made of bricks and tuff. The mausoleum is internally divided into six semicircular *arcosolia* arranged in pairs along three walls and richly decorated with paintings of peacocks and other birds or Nereids on sea monsters.

This study, developed within the research activities of PON SINAPSIS (www.progettosinapsis.it) was carried out using consolidated experimental methods, such as optical microscopy in polarized light (OM), colorimetry and X-ray diffraction analysis (XRPD) in order to achieve a deep knowledge on used geomaterials and pigments in the funerary monument. The results showed the presence and the wide use, as building stones, of mainly local materials, belonging to Phlegrean fields volcanic district lithotypes, such as Tufo Giallo Napoletano (NYT) and Phlegrean lavas. As far as artificial geomaterials are regarded, such as mortars, *cocciopesto* and bricks, the use of volcanic aggregates of local origin for these products is confirmed too. In particular, as concern mortars, the mix design is, in any case, the result of a mixture of lime and pozzolanic aggregates. Colorimetric analyses on painting (carried out both on original and restored surfaces), showed how the restoration treatments performed by the Conservation and Restoration Laboratory of the National Archaeological Museum of Naples, do not appreciably affected the gray/blue color, while determined perceptible and substantial changes to the red and yellow-ocher colors. As regards the composition of the pigments, the results of XRPD analysis allowed to affirm that the warm colors (red and yellow tones) were obtained using iron oxides; cool colors (blue and green) can be attributed, with good approximation, to the presence of copper; finally, the white color was obtained with calcium carbonate.

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Minero-petrographic and geochemical characterisation of pottery from Pompeii

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Keywords: carbonate ware, ferruginous ware, thin walled pottery, mineralogical analysis, Pompeii.

This study is focused on minero-petrographic and geochemical characterisation of pottery (1st BC – 1st AD) from the archaeological site of Pompeii, as part of collaboration between the team of the Università Federico II di Napoli (Italy) and that of the Berkley University of California (USA).

Nine samples representative of the main ceramic classes found during the excavation were analysed. Three samples belonging to carbonate ware (TED1, TED7, TED8), three to ferruginous ware (TED2, TED3, TED4), and three to thin walled pottery (TED5, TED6, TED9). A multi-analytical approach was used for the characterisation of the samples performing optical studies on thin sections, X-ray fluorescence spectroscopy (XRF), X-ray powder diffraction (XRPD), scanning electron microscopy (SEM) and energy-dispersion X-ray spectroscopy (EDS). Isotope analysis ($^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$) was pioneering applied to compare ceramics and raw materials.

The three ceramic classes show a similar volcanic temper but different chemical composition. The thin walled pottery and ferruginous ware show low-CaO concentration, while carbonate ware show high-CaO concentration. Garnet, with andradite-grossular composition, was identified in the ferruginous ware and in the thin walled pottery, while leucite was found in the carbonate ware. Presence of garnet or leucite in the three ceramic classes suggests the use of a temper derived from Somma products.

As far as clayey raw materials are concerned a chemical affinity with high-CaO clay from the village of Rufoli (Salerno) was noticed for the carbonate ware, as also evidenced by Sr and Nd isotope analysis, as already suggested by Peña some years ago.

On the other hand, ferruginous and thin walled potteries were produced with low-CaO clays. The identification of the source area of these raw materials is still debated. For these two ceramic classes could be hypothesized the use of weathered pyroclastic deposits, which mantle the Apennine range bordering the Campanian Plain, such as those from the Sorrento Peninsula still used in the today's traditional ceramic production.

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3-D pdf model of Gesualdo ancient centre (Avellino province): geomaterials and weathering

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Keywords: limestone, Breccia Irpina, albaster, 3-D pdf model, Gesualdo.

Gesualdo is an ancient centre located in the Avellino province. It has been built around the medieval castle dominating the Fredane valley. This ancient centre, whose name probably derives from the medieval word *Gisivaldum,* knew a new life and renaissance with the arrival of Carlo Gesualdo (1566-1613), also known as the Musician Prince, acknowledged as a leading composer of madrigals.

This study is based on a survey carried out by a team of geologists and architects as to reach a multidisciplinary knowledge of the town of Gesualdo, within the activities of METRICS project (Methodologies and Technologies for Management and Requalification of Historic Centers and Buildings).

The aim of this study is to a) highlight the main types of geomaterials (building stones, mortars and plasters) historically used at Gesualdo, which characterize its peculiar "genius loci", and b) develop a 3-D pdf model of this ancient centre.

The urban survey carried out by geologists took advantage of a detailed building map (street, places and buildings with their relatively height) elaborated by architects. The most important building stones identified in Gesualdo are: limestones, Breccia Irpina and alabaster. These materials crop out in the Avellino province, thus testifying the use of local raw materials in the historical built environment. Moreover, the plaster was often used on building façades.

The weathering displayed by geomaterials was subdivided in three classes: high, moderate and negligible, according to the relative extension of the decay.

Consequently, two different maps were produced, dealing with geomaterials and weathering grade, respectively, of an area in Gesualdo identified as representative of the traditional building techniques, according to the mapping procedures described by Calcaterra et al. (1995) and successive modifications.

On the basis of these information an important preliminary result was obtained, consisting of a 3-D pdf model which displays contemporary a) the structural and urban organisation of Gesualdo centre and b) information on geomaterials and weathering of buildings' façades. It is a quite simple graphical interface, a deliverable document which allows also non-expert users to visualize immediately the whole three-dimensional complexity of the urban shape along with information on building stones and their state of conservation.

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Graph theory applied to Laser Induced Breakdown Spectroscopy for the preliminary clustering of archaeological pottery

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Keywords: pottery, LIBS, Graph Theory, Neolithic.

The Laser-Induced Breakdown Spectroscopy (LIBS) is a methodology of investigation relatively fast and virtually non-destructive (Bertolini et al., 2006). Actually, it is an open system that can lend itself to many different applications and that can be integrated with other different methods for investigation of chemical elements. This technique is interesting for archeology for its ability to go in situ and its non-destructiveness (Ferretti et al., 2007), but also for the actual representation of the results obtained. In this paper, we applied the Graph Theory (GT) (Grifoni et al., 2016) to obtain a fast preliminary clustering of archaeological pottery. We have sampled and analyzed 32 fragments of pottery coming from the Neolithic site of Settefonti, Prata d'Ansidonia (AQ). The ceramic fragments all belong to the advanced stage of the culture of Ripoli (Ripoli III) in which the Settefonti site is a regional aspect very close to that already identified in Paterno.

We have investigated the fragments by LIBS for the acquisition of spectra, which represent the total chemical composition of the analyzed samples.

We compared the results obtained by this method with those obtained by the reading of the thin sections made by the same fragments. The results are discussed in a critical way in order to be able to understand whether the LIBS combined with the GT can be useful for a preliminary archaeometric clustering and if the results provided are in accord with petrographic results.

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Merging high-resolution bathymetry and 3D optical data for modelling a submerged archaeological site: a test from Capo Colonna onshore area, Crotone (Italy)

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Keywords: Multibeam swath bathymetry, optical images, virtual musealization, shipwreck.

Capo Colonna is a Greek-epoch archaeological site located in the East coast of Calabria (Southern Italy). The area was under the control of the ancient town of Kroton. Inland, there are the ruins of the Hera Lacinia sanctuary, which is considered one of the most important shrines of the Magna Graecia from the archaic Greek-epoch up to the fourth century BC. The area was also important in roman epoch for shipping from East Europe, as testified from so called "Punta Scifo D" shipwreck: a cargo of about 350 tons of ornamental stones discovered in 1986 in the surroundings of the Capo Colonna site at 7 m depth. These materials, which constitute the target of our investigation, were part of the cargo load from a roman vessel sunk in the 3rd Century A.C.. The vessel is actually not visible on the seafloor, probably because it has been completely destroyed from erosion and/or currents. However, specific study made on the cargo materials demonstrated that probably he was sailing from the island of Marmara (Turkey) and its dimensions were not less than 40 m in length and 14 m wide.

In this paper we present a method to combine the high resolution 2D and 3D data obtained from photogrammetric techniques with recent advances in the construction of acoustic, ultra high-resolution bathymetric maps in order to build three dimensional representations combining the resolution of optical sensors with the precision of acoustic bathymetric surveying techniques. The method for the opto-acoustic 3D reconstruction of the "Punta Scifo D" shipwreck and the surrounding seabed was carried out by merging a set of optical data that consists in more than 1200 images of the seafloor with the 0.03 m grid cell size Digital Terrain Model derived from multibeam swath bathymetry. To properly fit images from the seafloor with acoustic data, the scattered numb of measurements was used, in order to avoid small falsehood on depth measurements due to the envelope of contiguous cells on DTM. Bathymetric data shows typical sandy seafloor shapes (ripple) and a hummocky surface, made up from boulders with very different dimensions ranging from few cm until 18 m. Boulders are not randomly displaced on the seafloor, but rather organized to shape structures that maybe can be ascribed to ancient anthropic activity. The wreck area, in particular, extends 20x15 m and is made up by blocks of about 6 m. Blocks are partially buried, but some of them outcrops about 2 m from the seafloor. The obtained results show that the joined use of ultra-high resolution multibeam swath bathymetry and photogrammetric techniques is a good solution for obtaining an accurate representation of the underwater archeological site, and represents a useful tool for future purposes of virtual musealization of the maritime cultural heritage. This paper is funded by the VISAS project (www.visas-project.eu), co-founded by the Italian Ministry of Education, Universities and Research.

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Testing Greco-Roman medicinal minerals: the case study of solfataric alum

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Keywords: Greco-Roman medicinal minerals, solfataric alum; Melos, Greece, Campi Flegrei, Naples, antibacterial.

The medicinal properties of mineral pigments, mordants or washing powders presented in Pliny's 35th book of Natural History and in those of other authors of the Greco-Roman world (Galen, Dioscorides, Scribonius) have been relatively little researched compared to their botanical counterparts. Over the last fifteen years there has been detailed geoarchaeological prospections and chemical/mineralogical analyses allowed to identify some of these minerals in their recorded places, essentially of origin largely on volcanic islands in the Aegean (Photos-Jones & Hall, 2011). The medicinal minerals of antiquity are now understood to consist primarily of layered silicates, sulphates and metal oxides/sulphides (Photos-Jones et al., 2015). Recent studies have been also focused on (1) processing methods by which raw materials could have been converted to finished products, i.e. the medicinals, and (2) assaying for purity (Hall and Photos-Jones 2005; 2009; Photos-Jones and Hall 2010). Moreover microbiological work on layered silicates from some volcanic islands in the Aegean (Samos) and stamped archaeological earths (terra sigillata) (Lemnos) has shown them to be antibacterial (Photos-Jones et al., 2015). The present research focuses on the second group of medicinal minerals, namely sulphur and sulphates and in particular solfataric alum efflorescences from two volcanic landscapes, in Greece and Italy, i.e. Melos (Western Cyclades) and Campi Flegrei (Naples), respectively. Both regions are known to have been exploited in antiquity and later periods. The chemistry and mineralogy of a small number of geological samples collected from each are examined. For Melos, some samples have undergone field-based heating and processing while other samples have been used in microbiological testing. The results suggest that solfataric alum consists primarily of the minerals alunogen and K-alum with strong antibacterial (but not antifungal) properties. It is suggested that Greco-Roman medicinal minerals are likely to reflect long established geophagic practices incorporated within medical prescriptions, the antiquity of which may predate, by far, the historical periods. In addition, given that currently 'extreme' landscapes are the focus for the discovery of new drugs, an understanding of the nature and properties of the Greco-Roman medicinal minerals deriving from volcanic landscapes might be relevant to both antiquity and today.

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Three-dimensional survey and new forms of representation of the underwater cultural heritage. Island of Vivara

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Keywords: Exhibit Design, Tridimensional underwater survey, Archeology, Representation.

The experimentation about the employment of devices for tridimensional scanning and of dedicated softwares controlling machines and managing data is by now a permanent feature in the work of technologists, computer scientists and samplers.This kind of tool, be it laser, structured light or a software for image interpolation, in fact, permits to survey, with an accuracy to within one millimetre, tridimensional objects, whatever their forms and dimensions are, and to obtain digital models of the manufactures in the form of points – that we can describe as numerical-real since they correspond to the scanned objects with approximations known because referable to the acquisition systems. Thus they are substantially different from the virtual models which are, instead, produced by bidimensional data, namely plane information developed in 3d.

The acquisitions through these new technologies directly produce tridimensional information for a large amount of points which determine the totality of the surfaces of the object. The point clouds obtained, dynamically visible in real time, offer all of the spatial information concerning the manufacture, including their real image that, shot with calibrated cameras, is associated with them as texture.

However, what has been said is true for emerged objects but can hardly ever be verified in subaquatic, submerged sites since the normal surveying operations conducted in a static environment are not reproducible in a dynamic environment.

Nevertheless, the importance of the submerged objects and their large number, together with the difficulties connected to their detection, their study, monitoring and preservation in situ, as enshrined in the UNESCO Convention on the Protection of Underwater Cultural Heritage of 2001,have made it necessary to find a surveying technique capable of applying to them all the procedures followed for the emerged objects.

After careful consideration of these necessities, the University of Naples 'SuorOrsolaBenincasa' started the project SINAPSIS, PON01_01063, financed by MIUR, which aims at the creation of an integrated system in favour of the valorization, use and safeguard of the cultural heritage both emerged and submerged through the development of innovative solutions integrated with the already existing technologies.

Among its objectives Unisob had that of developing a tridimensional underwater scanning system, functioning through the elaboration of images, aimed at surveying the submerged archaeological sites and which could be integrated with the standard systems for the geomorphological surveying of coasts.

The research presents the results obtained from the tridimensional survey in the Gulf of Genito of the underwater archaeological site of Vivara, Procida, and the data management procedures for their communication in the exhibition area TERRA.

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Scientific investigation to compare different cleaning methods on archaeological pottery from the underwater site of Baia (Naples, Italy)

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Keywords: Decay, pottery, cleaning procedures, underwater archaeology, biological growth.

The decay of pottery in underwater environments is a complex phenomenon so far poorly investigated, since a multitude of factors is involved.

Degradation forms in seawater imply not only a variation in the physico-mechanical and chemical properties of the material, but also an aesthetic alteration, due to superficial deposits, which can determine to the illegibility of the artifacts. In this context, it is crucial to determine to what extent these decay factors, mainly attributable to biological growth, could affect the durability of pottery and what are the effects of cleaning procedures.

Several fragments of pottery from the submerged archaeological site of Baia (Naples, South Italy) were collected and subject to different investigations. The interaction between the biological colonization and the archaeological materials was evaluated by means of stereomicroscopy and scanning electron microscopy.

Then, considering that carbonatic encrustations are the main degradation products identified, some chemical and mechanical cleaning procedures have been tested for their removal. In order to check the most suitable method, some petrophysical properties were measured, such as surface roughness and ultrasonic velocity in order to evaluate change occurring in pottery properties after the removal of the degradation layers.

New antifouling products for in situ conservation of archaeological artificats located in underwewater environment

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Keywords: Archaeology, decay, antifouling, nanotecnology, siloxane wax, titanium dioxide, underwater.

This research is part of the national project entitled COMAS (Planned COnservation, ‘‘in situ’’, of underwater archaeological artefacts), concerning the degradation phenomena occurring during the permanence of archaeological items in underwater environment and their conservation in situ by means of new methodological approaches. In particular, the first topic of this study is to evaluate the rate and type of biological activity on marble stone specimens in seawater that, as well known, it changes according to the colonized substrate features. The second aim was to study the growth and the differences in biocolonization on treated stone materials and it is intended as a contribution to understand both the degradation forms resulting from biological activity and to test new protective products for the conservation of such materials, by using nanotechnology. Regarding nanotechnology, nanomaterials with antimicrobial and photocatalytic features were selected and undergone to experimental procedures with the aim of making antifouling products suitable for the protection of stone materials in underwater environment.

For the first time, nanomaterials (nano-powdered TiO_2, ZnO and Ag) were dispersed in siloxane wax (used as binder) in order to make possible the application of the products in underwater environment.

The experimental procedure was set up in the underwater archaeological park of Baia (Naples, Italy) in the area of the *Villa con ingresso a protiro*, on marble test-pieces, in order to compare the variation of biomass at increasing intervals of permanence in marine environment after being treated with different antifouling products. Laboratory procedures with the aim of assessing some specific properties of nanomaterials/binder mixtures as inhibitors of the marine biomass and their relation with the lithotype were carried out. In particular: colorimetric and contact angle measurements in addition with biological tests were performed. Later, several marble specimens were treated, anchored to a sample holder and immersed in the marine area of Baia. All samples were placed simultaneously and at increasing time intervals, some specimens were recovered and subjected to investigations. In particular, transmitted light optical microscopy and scanning electron microscopy (SEM) coupled with microanalysis (EDS) were used to study the biological colonization and the interactions with treated stone specimens, assessing the permanence of the antifouling products dispersed in wax and their effectiveness over time.

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Villa of *Pollio Felice*: characterization of mortars

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Keywords: Villa of Pollio Felice, mortars, mineralogical analysis, Neapolitan Yellow Tuff, Somma-Vesuvius.

This work was devoted to the characterization of mortars collected in the Roman Villa of Pollio Felice (commonly called *Bagni della Regina Giovanna*), situated in an important geological and archaeological area: Sorrento Peninsula (Naples). This villa was divided in *domus* and seaside *villa*; the entire complex covered almost thirty thousand square meters (Russo, 2006).

The goal of this work is to improve the knowledge of Roman construction techniques by means of detailed microstructural and compositional examinations of a) cementitious binding matrix and b) aggregates, to point out provenance of raw materials, mix-designs proportioning and secondary minerogenetic processes.

Thanks to the permission by Superintendence of Archeological Heritage of Campania, it was possible to take out small, non-invasive, and representative samples of mortars in order to reach our characterization scopes.

Mineralogical and petrographic characterization was carried out by: optical microscopy (OM) studies on thin sections, mechanical separation of different constituents (matrix, *cocciopesto*, aggregate) according to UNI 11305 procedures, X-ray powder diffraction (XRPD), scanning electron microscopy analysis (SEM), energy-dispersion X-ray spectroscopy (EDS), thermal analyses (DTA) and mercury intrusion porosimetry (MIP).

Composition of the cementitious binding matrix is particularly relevant, with the contemporary presence of gel-like C-A-S-H, derived from lime/"pozzolanic material", calcite, hydrocalumite, and gypsum. The presence of calcite is likely connected to incomplete reaction of underburned lime, although it is not possible to exclude that some carbonation occurred, from the residual portlandite, since mortars cured in a subaerial environment.

Hydrocalumite belongs to the family of double layered hydroxides. It is commonly synthesized by using calcium and aluminum salts. However, hydrocalumite could also be formed as major stable hydration product of cement paste and concrete or as secondary precipitate during the hydration of pozzolanic material (Tian & Guo, 2014). Finally gypsum could be ascribed to sulphatation processes of calcite.

Aggregate analyses highlighted marked differences between investigated mortars. Some samples showed presence of tuffaceous volcanic fragments ascribable to the Neapolitan Yellow Tuff deposit, confirmed by the presence of phillipsite, chabazite, and analcime. Other samples are characterized by volcanic aggregate linked to Somma-Vesuvius activity, due to the presence of leucite-bearing scoriae and garnet minerals. Several mortars showed presence of *cocciopesto*.

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The role of diagnostic analysis in the restoration of the Fontana di Trevi in Rome

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Keywords: diagnostic analysis, fontana di Trevi, restoration.

The Fontana di Trevi represents one of the most important monumental fountain of the city of Rome. The monument has undergone ~~to~~ a restoration in 2014-2015. In order to choose proper interventions, an extensive diagnostic analysis was planned, before and during the restoration. This activity was carried out in collaboration with the restorers and with the restoration project manager.

In order to check the state of conservation of the stone materials, several micro-samples have been taken and then subjected to several analytical techniques, such as petrographic, mineralogical and microchemical analysis. Results suggested the degradation processes taking place into this characteristic microenvironment, in which water and stone are constantly in contact, originating a continuous solubilisation-deposition effect within the stone materials, this can heavily affect the original shapes of the monument. In addition, the analyses allowed distinguishing between the original materials and those superimposed during previous restoration procedures.

Moreover, there was a debate among the stakeholders about the colors of some surfaces. One issue regarded the orange colored niche were the statue of Oceano is located. There was a doubt about the origin of such color, since it was unclear if it is original or it is consequence of a degradation process. The scientific investigation, carried out by checking the stratigraphy and the presence of pigments, revealed a deliberate intention to give a warmer tone to this architectural element. Similar issues have been faced on other portions, such as on some statues, or on plasters. In some cases the colored layers have been identified as a degradation product, therefore, they have been toned down in order to keep the overall harmony of the monument.

An Inventory Proposal For the Conservation of a Historical Anti-Seismic System

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Keywords: 1783 earthquake, Borbone anti-seismic system, Conservation of cultural heritage, Cultural Heritage.

A terrible earthquake struck the Calabria region (South Italy), on 5th February 1783. The consequences were devastating with numerous completely destruct villages, the economy annihilated and many victims.

The Borbone government, among several measures, decreed that the reconstruction had to be realized with technologies aimed at mitigating the seismic vulnerability of the building. For this purpose the rule imposed the use of a timber framing inside the masonry in order to provide an additional traction resistance to the wall and to achieve a connection among the structural elements of the building.

Such a constructive system has showed a proper behaviour under cyclic actions during an experimental campaign on full scale samples carried out at the CNR Ivalsa laboratories (Ruggieri et al., 2015). Furthermore, the analysis of the damage modes caused by the 1905 and 1908 earthquakes, described in historical chronicles and photos, has highlighted limited cracks and deformations mainly interesting, anyway, the masonry (Ruggieri et al., 2013).

The Borbone system due to its uniqueness, by virtue of being a fundamental chapter in the history of the anti-seismic engineering and of the science development in Europe, has to be conserved in the original materials, in the static scheme, and, in general, in all its technologic connotations. Unfortunately, many of these 18th C structures experience a state of abandon that, added to the timber intrinsic vulnerability, moderately durable if it is embraced by an environment characterized by a potential high moisture content, as the masonry, is provoking an inexorable loss of that heritage of inestimable value.

Measures aimed at conserving and transmitting to the future generations such a historical constructive system are immediately mandatory.

An essential tool for the conservation, generally speaking, of the cultural heritage, is its widespread knowledge. To that purpose this contribution proposes a template aimed at inventorying surviving Borbone buildings.

The template follows a tree-like structure, so that information can be recorded from the scale of the whole construction to the single parts constituting the wooden framed masonry. It includes the geometrical features of the building emphasizing possible irregularities in plan and along the height, from which torsional motions could trigger under earthquakes. Other fields of the template follow the hierarchical organization that characterizes wooden structure divided in members and structural units connected by joints and auxiliary beams to form a structural system (Tampone, 1997). For such combination the template provides data on the geometry, dimensions and regarding materials features relatively to the stone and mortar type and to the wooden specie of the framing. The degrade is also listed, divided in that derived from causes of mechanical nature and due to biotical agent, deducing the reliability level of the load bearing structure.

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Environment and cultural heritage interaction: current state and future perspectives

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Keywords: Cultural heritage, Climate change, Air pollution.

Atmospheric and climate sciences have substantially contributed to scientific research applied to the protection of cultural heritage towards environmental impact. Relevant research results developed in this sector will be presented, concerning in particular the future scenarios and the impact evaluations of air pollution and climate change on cultural assets, both indoor and outdoor located.

Despite the strong interest focused on these areas, both at research and policy levels, very little attention has so far been directed towards the impact of future change on cultural heritage: this is unacceptable either in Europe and in Italy being cultural heritage a non-renewable resource to be transmitted to future generations.

In order to fill this gap, an innovative research work has been realized within the Noah's Ark Project, funded by the European Commission, which produced, as results, the "Atlas of climate change impact on European Cultural Heritage".

The study performed included as initial step the identification of the most relevant climate parameters affecting cultural heritage (e.g. yearly precipitation, rainfall intensity) for producing climate maps. Subsequently, the parameters were combined to produce specific heritage climatology, e.g. wet-frost, based on rain followed by intense freezing, allowing the preparation of the heritage climate maps. A further step employed climate parameters to determine the amount of damage occurring on building materials in future scenarios, and to obtain the damage maps (e.g. stone surface recession, metal corrosion). Finally risk maps were prepared combining two or more damage processes that could occur in different regions of Europe. Guidelines were also formulated in order to inform cultural heritage managers and stakeholders on the effects of climate change on built heritage. The presentation will summarize some of the results achieved.

As described, the Italian scientific community has played and is currently playing a leading role in this area of research not only in Europe, but globally.

In fact, recently, our Institute started a collaboration work in order to study the environmental impact in extra-Europe areas, in particular in Panama, Central America, where the climate change can have a different effect on the monuments exposed to that latitudes. This study can enhance the knowledge in facing extreme events and it will support the preservation of UNESCO sites located in this region.

Finally, the presentation will also include the summary of the activities implemented by the Joint Programming Initiative "Cultural Heritage and Climate Change: a new challenge" coordinated by Italy, specifically the Ministry of Education, University and Research-MIUR and the Ministry of Cultural Heritage and Activities and Tourism-MIBACT, since 2010 with 18 EU Participating Countries.

The composition of the ancient Calvello ceramics (Basilicata, southern Italy): preliminary results

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Keywords: Ancient ceramics, mineralogy, petrography, Calvello.

The composition of ancient ceramics is of common interest for archaeologists and scientists that investigate the technological aspects of pottery production processes as well as the nature and provenance of raw materials. In this paper we present the results of a preliminary study on two ceramic artifacts likely dating back to 18th century. The artifacts, here studied for the first time, are from the Calvello town, southern Italy (Basilicata Region), which boasts a very long tradition in the ceramic manufacturing. The analysed samples are a portion of two rectangular, uncoated floor tiles (5 x 15 x 3 cm) showing reddish to brownish colour and rough surface. According to the classification scheme proposed by Whitbread (1986) and based on the optical microscopic observations, only one petrographic fabric for both samples was identified. The fabric is characterized by a porosity of about 10% of the total volume mainly consisting of meso-vesicles and rare meso-vughs (0.05 to 0.5 mm in size), not aligned to the margin of the sample. The artifacts are composed by a fine (<0.5 mm), clayey, low birefringence paste matrix containing well distinguishable micrometre mineral inclusions. The inclusions, corresponding to 5-10% of the total volume, consist of crystals of quartz, feldspars (K-feldspars and plagioclase with albite twinning), micas (mainly biotite, rarely muscovite), iron oxides, calcite and opaque minerals. In order to define the mineralogical composition of ceramics carefully, the X-ray diffraction analysis was also performed on powdered artifacts. The XRPD results on the hand confirmed the mineralogical assemblage already identified by petrographic analysis, on the other hand documented the presence of further mineralogical phases, such as clinopyroxene (diopside) and ghelenite. It is worth noting that these minerals commonly formed by reaction between silicates and carbonates during the pottery firing and therefore they have a great importance for the technological research. In our case, the presence of calcite and clay minerals in association with gehlenite, diopside and anorthite, suggests the Calvello ceramics during their manufacturing achieved a medium-high firing temperature with the maximum temperature of about 800-850°C. A further step of the research will focuse on the chemical composition of the artifacts and their metal contents to better evaluate some relevant archeometric features.

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Chemical and textural investigations on medieval slags from "ex-Monte di Pietà" archaeological site (Emilia-Romagna, Italy)

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Keywords: medieval slags, Forlì, archaeometric investigations.

The aim of this work is to report chemical and textural analyses on archaeometallurgical slags from the medieval Forlì in north Italy. Between February 2004 and August 2005 the "Cassa dei Risparmi di Forlì" Foundation successfully exploited the "Ex-Monte di Pietà" archaeological site. Twenty-two slag specimens were collected from ancient rubbish dumps that accumulated scraps from craftsmen workshops over about four centuries (Guarnieri, 2009). Slags were analysed by X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy and energy dispersive X-ray spectrometry (SEM/EDS).

The obtained results highlighted slags deriving from the production of both iron and copper; moreover, severely corroded iron nails was identified. In this paper, the chemical and textural characterisations of ferrous slags and nails will be discussed.

Ferrous slags were glassy in aspect with quartz and charcoal fragments embedded into the matrix. The matrix was mostly formed by silicon, iron, calcium and aluminium; other elements that do not enter crystalline silicates, i.e. potassium from the charcoal and sulphur from the mineral charge were also detected. The most abundant phases in the glassy matrix were monticellite, wollastonite, fayalite, wüstite, sulphides, metals and metal alloys. The minerals probably underwent a roasting prior to smelting; moreover, melting agent was added to the mineral charge. Metallographic observations of the olivine habit and size distribution have provided information on the cooling process. In particular, olivines ranged from polyhedral-granular to acicular indicating a cooling rate of the melt lower than 60 °C/h (Ettler et al., 2009) The slag also contained large amounts of dendritic iron oxides as could be expected from the iron-rich bulk chemical compositions.

Nails consisted of an iron-rich core about 0.5 cm in diameter. The elemental composition well evidenced the structure of the core, where crystallised magnetite was admixed with a greater amount of crystalline maghemite. The core lied beneath ferrous oxides, ferrous hydroxides and silicates/phosphates-enriched layers probably due to fluctuations in piezometric level of the acquifer. XRD analyses enabled wustite, goethite, ferrosilite, lazulite and quartz to be distinguished (Booth et al., 1962).

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Guarnieri C. 2009. Il Monte prima del Monte. Archeologia e storia di un quartiere medievale di Forlì. Ante Quem, Bologna.

Technologies of intervention and management of the remains of the villa of Gneo Fonteo (first century BC) in Gaeta (central Italy)

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Keywords: Coastal area, Archaeological site, Non-destructive surveys, Gaeta, Central Italy.

The western coast of Gaeta in central Italy shows a succession of prominent headlands with plunging cliffs and coves with beautiful beaches. The rocks exposed on the headlands and along the slopes rather steep, are represented by a succession of white limestone Cretaceous in age. On these rocks, modelled and karstfied in the Quaternary, there are typically discontinuous strips of limestone debris or more extensively layers of reddish Pleistocene eolian sands (De Pippo et al., 2007). The favorable climatic conditions of this suggestive coast favored vacationing since Roman time.

In one of the smallest cove the remains of a magnificent Roman villa of the first century BC are still preserved. In the inlet, arranged radially at few meters from the sea level, you can see the so-called Fontania caves, small rectangular openings of various depths, which originally were to serve as storage for the private marina (Tallini, 2006). These rooms, carved into the limestone cliffs widening preexistent small caves, are contiguous to the beach. They are used to bathing purposes, and are overlapped by sandy-detrital soils on which they were made in the last few decades several villas with appurtenances. Probably this condition may have determined phenomena of infiltration and this can endanger the stability of the underlying caves (landslides in 1985 and 2014) and consequently raising the degree of landslide hazard in this area. In order to establish the degree of danger affecting the Roman structures were carried out a series of surveys on this site.

Such surveys consist in non-destructive surveys and tests carried out on the cliffs of the inlet as well as on the structure of the Fontania caves to check their stress state. To estimate the stability of the limestone cliff that borders the site under investigation was performed a detailed geomechanical survey in order to classify the various discontinuities in the rock mass and to identify the parameters that influence the mechanical behavior. To provide information on the underground soil and to the integrity of the caves geophysical superficial surveys (geoelectric and Ground Probing Radar profiles) were executed. At last, a structural analysis of the cavities, already used in Roman times with barrel vaults and limestone walls partially covered by opus reticulatum, were done (Kamal et al., 2014). All the survey results indicate the absence of critical conditions and encourage instruments and measures for the protection, use and promotion of these vestiges of the Roman epoch.

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Multianalytical investigation for dating purpose of contemporary artworks: test case on "Cubist Figure", attributed to Pablo Picasso

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Keywords: Dating, pigments, painting, chemical-physical-mineralogical analysis.

In the field of Cultural Heritage, scientific studies provide useful information not only for conservative purpose and restoration projects but also to support dating and authentication studies. The identification of artistic techniques and materials is always more frequently combined to traditional stylistic and historical sources studies, especially for the assessment of authenticity of paintings. Generally, traditional investigation on "dating pigments" demonstrated to be very efficient in particular for ancient artworks, but in depth pigments analysis allow to furnish interesting data also for contemporary paintings. In fact, data about the morphology of pigments particles, chemical – mineralogical composition, etc. permit to better understand the origin of pigments (natural or artificial, ancient or modern, etc.) and, therefore, to exploit pigments timeline for dating purpose.

The present studies shows results obtained by a recent research carried out on "Cubist Figure" (oil on canvas), painting attributed to Pablo Picasso (1881-1973) (Volpe L., 2013). The painting belongs to a private collection and it contains the main characteristics of the Analytical Cubism, one of the two major branches of the artistic movement of Cubism, developed between 1908 and 1912 (Golding J. 1988.).

The numbers "09", drawn after the signature "Picasso", suggested that the artwork dates 1909 but scientific research have been combined to artistic and stylistic studies for a more precise dating of the paintings.

This study consists of a multi-analytical approach with the aim to obtain chemical-physical-mineralogical information in order to identify pigment peculiarities related to different time and production methods of pictorial materials. Considering the results obtained by preliminary chemical analysis (Bruni S. et al., 2012), several analysis were performed on white and blue microsamples, taken from original area and near the borders of the painting. In particular PIXE, EDXRF analysis were carried out to obtain more precise and detailed chemical composition and Micro-raman, XRD for a deep mineralogical characterization.

In conclusion, the results of this research provide useful information about artistic technique and materials employed by Pablo Picasso, verifying also the compatibility between used pigments and the suggested date.

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SESSION S35

Three centuries of Geology in Italy

CONVENERS AND CHAIRPERSONS

Marco Pantaloni (ISPRA Roma)
Alessio Argentieri (Città Metropolitana di Roma Capitale)
Gianbattista Vai (Museo Capellini Bologna)
Ezio Vaccari (Università dell'Insubria)
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Illustrating and mapping Etna's eruptions: from the iconographies of XVIII century to the modern geological cartography

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Keywords: Etna, iconography, geological cartography, historical eruptions.

The knowledge of Etna's eruptions has been profoundly influenced by the illustrations, though these can only provide limited information on the lava flows and their effects on the territory. Indeed, the absence of iconographic sources or the disparity between the physical reality and the illustrations has led to many gaps and uncertainties that have lasted for centuries.

This work traces the progress of the representations of the historical eruptions of Etna volcano, from the earliest attempts in the 18th century, be they iconographic documents or pictorial illustrations, to the modern geological cartography of 21th century (Abate & Branca, 2015). The thread running throughout this history is the presence of both the temporal and spatial dimensions. Time in the graphic rendering of the paths taken by the lava in the past, space in that each map is an expression of the changing morphology of the volcano. These were the common factors in selecting the drawings, paintings and maps presented here, with an understanding, beyond applying an exclusively iconic interpretation, that they reconstruct the evolution of the history and methods of representing etnean eruptions, highlighting the crucial steps in the progress of knowledge on the historical eruptive activity of Etna.

The turning point in the long process of drafting and rendering the eruptions of Etna came with the work of Sartorius von Waltershausen (1848-61), with the realization between 1836 and 1843 of the first geological map of the volcano at a 1:50,000 scale. The accuracy of the geological surveys of Sartorius undertook in mapping the historical lava flows means that even today, more than a century and a half later, his maps are still used by researchers to extract the volcanological parameters of eruptions whose traces have disappeared from the territory after successive eruptions. In this long history of the representations of eruptions, begun in the 18th century, Sartorius' cartography finally overcomes the problem of rendering these events in space by inserting the notion of history in the map. What now remained for those engaged in mapping the volcano was to solve the issue of defining the "time" of Etna's historical lava flows. This would be tackled only at the end of the 20th century with a multidisciplinary approach comprising stratigraphy, historiographical studies and the dating of the lavas during the realization of the geological map at 1:50,000 scale of Etna (Branca et al., 2009) in the frame of the national geological cartography to draft the new geological map of Italy.

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Urban geology in Rome's natural laboratory: Ugo Ventriglia's legacy

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Keywords: Rome, urban geology, history of geology.

Since 18th century Rome represented a natural laboratory for the development of geological studies in urban areas. The peculiar geological framework of the Eternal City is related to the tectono-sedimentary evolution of the Tyrrhenian margin of Central Apennines, affected in particular by strong volcanic activity during Quaternary. Moreover, three millenniums of human activity induced permanent "bioturbation" of natural environment of the roman area, thus creating a unique scenario attracting the interest of naturalists, geologists and archaeologists in the last three centuries. Starting to the famous map of G.B. Brocchi (1820), systematic studies of the town territory and of its underground have been carried out, aimed to provide a useful tool for sustainable land-use planning and urban development. A pioneer of the modern approach to this issue was undoubtedly Ugo Ventriglia (Rome 1916-2005), who spent most of his career studying geology and hydrogeology of Rome and its environs, which he described in several voluminous monographies published by the Province of Rome (1971; 1988-90; 2002). His masterpiece "La geologia della Città di Roma", published in 1971, represented for a long time a fundamental reference for researchers and technicians, until new studies, arising from the CARG project, came out later on (Funiciello et al., 1995, 2008; Serv. Geol. d'It., 2008).

The main value of Ventriglia's scientific production descends from his great accuracy in collecting and cataloguing geological data. Such information, kept independent from subjective interpretations, is thus a treasure whose reliability persists through time (Argentieri, 2015). On the occasion of Ugo Ventriglia's birth centenary, the Metropolitan City of Capital Rome wants therefore to celebrate the scientist and the precious legacy he left to the local community.

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Portrait of a bow-tie wearing gentleman: Achille Zuccari, General Secretary of the Italian Geological Society

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Keywords: geomorphology, glaciology, Italian Geological Society.

For almost fifty years spirit and core values of the Italian Geological Society have been preserved with the help of a particular person: his historical General Secretary Achille Zuccari (1926-2015). Firstly, after long time, a general assembly of our institution takes place without the bow-tie wearing gentleman and his inseparable Tuscan cigar. The History of Geology Section has therefore organized a commemoration during the Session "Three centuries of geology in Italy", collecting testimonies of Achille's colleagues and friends. In our vision, progress of science depends from the contribution of all the members of a community, including those working not in the spotlight.

Born in Rome in 1926, he spent his childhood in Littoria (nowadays Latina) and then moved to Rome gaining his high school diploma at "Cavour" Scientific Lyceum. As a working student- since 1952 he was employee of the national telephone company- Zuccari graduated in Geological Sciences at the University of Rome "La Sapienza" in 1959, under the guide of Carmelo Maxia, with a thesis on the geology of middle Aniene River valley. In 1962 he married Anna Tilia, a girl met in the childhood, who became a micropalaeontologist and stratigrapher under the guide of Angiola Maria Maccagno. In the same year Zuccari was appointed Cavalier of the Italian Republic by President Antonio Segni.

In the earlier part of his career he published a few papers concerning the geomorphology of the Aniene Basin (Zuccari, 1963; Avena et al., 1967, 1968), contributing in those years to the development of that discipline in central Italy, in cooperation with Elvidio Lupia Palmieri and Giancarlo Avena. In the '60s he was assistant of Roberto Colacicchi and joined the Italian Glaciological Committee, participating to several scientific campaigns during that decade. At the end of this period he passed the qualifying exam to become a university professor.

Member of the Italian Geological Society since 1955, he was firstly Treasurer and Secretary (1967-69) and then General Secretary, continuously from 1970 to 2011. As a consequence of the charge, since 1967 he was also Editorial Manager of the SGI publications.

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1932: a historical database of natural and anthropogenic cavities in the Province of Rome

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Keywords: anthropogenic cavities, caves, Province of Rome, sinkholes.

In the historical archive of the "Città Metropolitana di Roma Capitale" (the former "Provincia di Roma") an interesting typescript dated 1932 was recently found, representing one of the first modern catalogues of karst and anthropogenic landforms of Latium. Author of the unpublished document was Vittorio Ferrari, at the time Chief Engineer of the Technical Department of the Province of Rome. The typescript contains a list of features known in the territory, and includes a 1:200.000 scale map with location of caves, natural cavities, classified in order of importance, sinkholes, karst depressions, artificial cavities of archaeological importance, ancient quarries, mineral and thermal springs. The study regards the entire territory of the province of Rome, in its original extension, established in 1870, corresponding to almost to the whole current Latium area.

The topographic base is the 1931 Road Map of the Province of Rome, being the study performed for engineering purposes. Road works were indeed the main tasks of the technical office directed by Ferrari, who wrote several reports on this topic; two of them (one presented at the 9th International Road Congress in Lisbon in 1951) are kept in the historical archive of the Province.

In spite of his technical purpose, the scientific peculiarity of Ferrari's paper consists in its systematic approach to territory knowledge, being one of the first catalogues of Latium cavities and anticipating the study of Segre (1948) published almost two decades after. Karst phenomena studies of this region, mainly performed by speleological associations, started in fact in the early 20th century; Ferrari, member of an authority having a marginal knowledge of this theme, probably prepared his work independently. Forty years later, this expression of interest of the technical offices of the Province of Rome for cavities mapping was renewed by the cooperation with Ugo Ventriglia, which in 1971 started publishing important monographs concerning that territory, supported by the Province Geological Survey (Argentieri, 2015). A modern complete catalogue for the whole Latium region was finally performed by Mecchia et al. (2003).

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Egidio Feruglio, a geologist of the two worlds

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Keywords: Egidio Feruglio, palaeontology, history, geosciences, Patagonia.

During reorganization and movement of palaeontological collections to the upcoming MUST (Museo Universitario di Scienze della Terra), fossil specimens were routinely pulled out of drawers and dusted. Some of them were found carefully combined with labels unequivocally referring to Egidio Feruglio (1897–1954), which is one of the most prominent and polyhedral explorers of the first half of the last century that Italy and South America may count. Summoned by Guido Bonarelli in 1924, Feruglio chose to contest and refuse in his own way to adhere to the Partito Nazionale Fascista, pursuing South-America the next year. From that time, he embodied the wave of migrations to Argentina and back to Italy that, after him, involved some others Italian contemporaries geoscientists. The labels and the manuscript draft he used to hold fossils represent a significant treasure chest, which allowed to precisely reconstructing a bit of his seemingly unflagging and perpetual survey up and down around Patagonia. We were able to trace back, from Feruglio's notes, few significative field stops occurred at the turn and at the end of the thirties (three years after his second 'voluntary' exile). The fossil specimens that supposedly arrived with him in Rome were collected from different Mesozoic and Cainozoic ages, across about ten localities of central and austral Patagonia (e.g. Comodoro Rivadavia-Chubut, Lago Argentino, Lago Viedma), probably firstly explored during A. De Agostini's expedition. Beyond this intriguing research, the finding elicited our interest in understanding the natural stature of Feruglio, starting from the material he collected. Being valuable testimony of the boundless interests and devotion to science of the man called 'Stratigrapher of Patagonia', which is rightfully celebrated in several pure biographies, Feruglio's Argentinean material also constitutes an exceptional transoceanic 'Arianna wire' joining alternative homelands by the personal adventures of a single great gentleman. From a broader standpoint, that material epitomize and recap still today Feruglio's intellectual legacy, rigorously based in favour of the community, irrespectively of blood, as confirmed by the MEF (Museo Egidio Feruglio, Trelew, Patagonia), which remember him as a 'extranjero definitivamente incorporado a la historia del país'.

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Giacinto Provana di Collegno, a pioneer in Italian Geology

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Keywords: Enlightenment, Risorgimento, Piedmont, Earth Sciences, geological map.

The Italian geological cartography is the result of a complex, multi-faced work of synthesis, entwined with historical facts and the evolution of the scientific thought which started in the second half of the 18th century. Considering that such synthesis began in a highly fragmented political environment made up of many small independent states, which were often in conflict with one another, the Italian geologists who carried out this challenging work must be held in the highest admiration for their commitment and their passion. Among these, Giacinto Provana di Collegno (Torino 1794 – Baveno 1856) deserves particular consideration. He lived an adventurous life in un age permeated by the spirit of the Enlightenment and by revolutionary aspirations which he absorbed and lived with romantic passion. At a young age he studied at the Tolomei's College in Siena, where he developed an interest for geology in particular, greatly encouraged by a genuine interest for natural science on the part of his religious teachers. These were modern ideas which were very important for his career. When he left school, he became an army officer who played an active part in the Italian Risorgimento, but he was also a naturalist and a geologist, participating in political and scientific activities at international level. Having taken part in revolutionary activities in Piedmont in 1821 he was exiled. While in Paris, in 1835 he enrolled in the University and earned a degree in geology at the age of 44. This marked the beginning of a fruitful career as a scientist with an abundant production of studies in many fields of the earth sciences (stratigraphy and paleontology, quaternary geomorphology, mineralogy, mining and fuel resources...), in several European regions (Pyrenees, Gironde, England, Scotland, Scandinavia, Alps...). He is also renowned for the French translation of important works in geology, such as "How to observe Geology" by Henry T. de la Bêche published in Paris in 1838 with the title "L'art d'observer en géologie" contributing to the spread of new scientific theories. Not less remarkable was his teaching career, first at the University of Bordeaux (1838) and then at the prestigious university of Florence, where he was offered a teaching post by the government of Tuscany in 1845. This event marks his definitive return to Italy, following his exile and pardon granted by King Carlo Alberto. Here he carried out several geological studies about Tuscany, Liguria and Piedmont, while his dedication as a scientist entwined again with his interest as a politician, dreaming of a United Italy. His commitment to this cause, culminates in the compilation of the first geological map of the Italian peninsula, "Esquisse d'une carte géologique d'Italie", published in Paris in 1846 to scale 1: 2.000.000. It was a summary of all the cartographical knowledge acquired by a number of his scientific colleagues, a sort of "Geological Unity of Italy" just a few years before the political unification of the country.

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Exploring mountains: The geological travel of Paolo Sangiorgio in Valsassina (1770)

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Keywords: Paolo Sangiorgio, Alps and Prealps, mining, history of geology.

During the second half of the Eighteenth century, mining and mineral knowledge fostered significantly the gradual formation of geological sciences, allowed them to reach an own epistemic value definitively. The 'institutional recognition' of Earth Sciences, and especially between the Eighteenth and Nineteenth century, was certainly made possible by the spread of rather common scientific behaviours, which were mainly based on fieldwork. Dealing firstly with some strategic and economic needs, the well-known practice of the geological travel in Italy undoubtedly allowed a deep knowledge of given territories and their natural resources but, at the same time, it provided an essential impetus for launching scientific debates on geological phenomena, such as orogenesis and physical processes of ore deposit formation. Against this backdrop, the scientific survey and, consequently, knowledge of the Alps and Prealps took place, involving several Italian as well as European scholars between the Eighteenth and Nineteenth century. Beginning with considerations on his unpublished manuscript about the mineralogical travel he undertook in Valsassina (Lake of Como, Northern Italy) in 1770 (*Relazione D'un Viaggio fatto nella Valsassina e sopra li Monti del Lago di Como A ordine di Sua Eccellenza il Sig. Conte di Firmian Ministro Plenipotenziario Nella Lombardia Austriaca*), my contribution aims at analyzing the mostly unknown work of the Italian *savant* Paolo Sangiorgio (Milano 1748–1816).

The birth of Petrography

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Keywords: Petrography, Natural History, taxonomic basis.

In the first decades of the 19th century G. Arduino, G. Marzari Pencati, and G. Brocchi, italian experts in mineral exploitation, correctly recognized the igneous nature of either intrusive or volcanic bodies within sedimentary sequences on the grounds of field data (Bianchi, 1934), in contrast to Werner's neptunistic ideas. Petrography was then growing as an autonomous discipline from Mineralogy and Geology, within the frame of Natural History, due to the basic works by Cordier (1816), von Leonhard (1823), and Brongniart (1827), who introduced a taxonomic basis, although affected by inconsistencies and naiveties, related to rocks on the grounds of their compositions and origins, after Werner (1774) had subdivided rocks into groups meeting some criteria of petrograhical taxonomy, although chiefly based on purely stratigraphic principles. A millennial gestation was thus accomplished, supported by the growth of scientific knowledge and of investigation methods and techniques, that had a start in the closely preceding centuries. As a first attempt of modern rock classification Linnaeus introduced the chapter Rocks (*Petrae*) of the *Regnum lapideum* in his *Systema Naturae* (1735). This model based on genuses and species, although unfit for objects of the inorganic realm, was initially used by numerous scholars (e.g. Haüy, 1822).

In the previous centuries and millennia rocks and minerals (cf. Cirrincione, 2015) were considered and classified depending on how they appear or can be used as such (building materials, gems) or as raw materials to be worked in order to get other ones (ceramic ware, terracotta, glass, metals,...). Georg Bauer (1494 –1555, *Georgius Agricola*; *De Natura Fossilium*, *De Re Metallica*), Avicenna (980-1037; *Kitab Al-Shifa* with the most ancient known minero-petrographic taxonomy), Pliny the Elder (23-79 d.C.; *Naturalis Historia*), Theophrastos of Eresos (372-287 a.C.; *Peri lithon*) may be included within this frame due also to the effects they had in the later gradually developing concepts and knowledge.

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Geological mapping in Calabria in XIX century

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Keywords: Calabria, History of geology, geological mapping.

It is a widely diffused opinion that the knowledge of the geologic characters of the Calabrian territory may be referred to the early XX century; nevertheless, a thorough investigation carried out in the cartographic collection of the ISPRA Library, that preserves the historical cartographic heritage of the Geologic Survey of Italy, allowed to regain and analyze original XIX century cartographic material of undoubtedly scientific interest.

The precursor of all geologic studies in Calabria was L. Pilla, who was the first in 1836 to raise the issue of the relationships between the intrusive units of the Aspromonte and the sedimentary successions of the Thyrrenian and Ionian sides. In 1840, the german naturalist R.A. Philippi, inspired by Pilla's work, published the paper "Geognostische Skizze Kalabriens" translated and published in Italian by G. Del Re. Appended to the handwritten translation we have found three geological sketches of the Calabrian region, of uncertain attribution that probably were preparatory drafts for a final publication.

Another surprising finding of our research was the discovery of a map and a document drawn up by S. Giancossi. In his "*Descrizione geologica della Calabria Ultra Prima*" written in 1867, Giancossi highlights the peculiar character of the Calabrian geology beginning with a very incisive claim: "*Descrivere la Calabria Prima sotto al riguardo geologico sarebbe lo stesso che ripetere quasi tutte le specie di rocce dall'epoca cristallina fino alla più recente diluviana giacchè quasi tutte sono contenute […] in questa piccola parte estrema della penisola italiana*". Being the latter work almost ignored by the scientific community, the interest for the geology of Calabria was successively renewed, first by G. Vom Rath (1871-73) and then by V. Rambotti, which in 1877 realized a valuable *"Piano geologico lungo il litorale Ionio fra Cariati e Monasterace*" for the realization of the Taranto - Reggio railway.

In the last decade of the XIX century, just prior to the publication of the Calabrian sheets of the official cartographic map at 1:100.000 scale of the Geologic Survey of Italy, many projects of geological mapping were carried out by several geologists, including C. De Stefani, R. Fucini, G. Seguenza and, above all, D. Lovisato.

Between 1878 and 1881 Lovisato, charged by the Royal Geologic Committee, realized a geological map in 32 sheets of Northern Calabria on the 1:50.000 scale, that represents the first geological map of the region conceived in a modern way. Undoubtedly, this work was the milestone for the production of the official cartography, realized since 1895 under the direction of E. Cortese.

Cultural climate in Naples between the birth and development of volcanology

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Keywords: Volcanology, Uniformitarism and Gradualism, Vesuvius.

Between the end of the 18th century and the mid-19th Europe was experiencing great changes brought about by two industrial revolutions. The first began in the early 18th century when there were deep-rooted changes in England in the means of production: new sources of raw materials were being exploited, new markets opened, the population grew considerably, and there were significant changes in the structure of society. In the second industrial revolution in the mid-19th century the main driver for development would be scientific discoveries.

The industrial revolutions changed the approach to natural phenomena. Such events were to be measured with physical laws and represented with thematic maps. In this context the Vesuvian Observatory emerged; it would become the first observatory to tackle the problem of monitoring volcanic phenomena. In Naples geology would remain chiefly volcanology: thus chemists, physicists, geologists, mineralogists and naturalists approached the study of volcanoes by developing feedback between the science of laws and that of processes. With the emergence of geological theories of uniformitarism and gradualism of Hutton and Lyell there would arise the conflict between geologists and physicists on the time required to interpret geological phenomena and Darwinian evolution. The hub of the question was resolved with the discovery of natural radioactivity in the early years of the 20th century which would allow the age of the Earth to be extended to billions of years. The new quantitative approach to studying natural phenomena was to find fertile ground in Italy for the analysis of seismicity, with the creation of the first seismic networks and quantification of events through scales of intensity. Naples became an attractor for scholars, due to the presence of the Vesuvian Observatory and the permanent activity of Vesuvius, the dynamics of the Campi Flegrei, the thermalism of Ischia and the interaction between volcanic phenomena and ancient settlements.

After World War I interest in Naples-based volcanology grew further, as attested by the opening in the city of Immanuel Friedlaender's International Institute of Volcanology and the Central Office of the Volcanology Division of the International Geodetic and Geophysics Union moving to the Vesuvian Observatory.

Following the twenty-year Fascist period and its defeat in World War II, Italy had two objectives: to reconstruct the network of science laboratories both within and outside universities and re-establish the approach to studying Earth Sciences through comparison with more advanced countries. Both objectives were achieved, the country becoming competitive in various research sectors also in Earth Sciences. Significant contributions were made to the new theory of global tectonics, while original contributions were made to the mitigation of natural risks.

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When the Geological Survey of Italy goes underwater

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Keywords: geologic maps, marine geology, sea-floor, sedimentology, geophysical surveys.

The Geological Survey of Italy (at that time Mining Department of the Ministry of Industry, Trade and Craft) started to investigate seabottoms at the end of the '60s by scuba diving. Its task was to implement the geomorphological and geomineral knowledge of the seafloor, aimed at the realization of thematic and "special" maps to complete the geological map in areas of mining interest.

Later, in the frame of the CNR (National Research Council) Targeted Project "Oceanography and seafloor", sub-project "Placers", sampling and remote sensing acquisition was performed on board of the Oceanographic vessels of the CNR (Marsili, Bannock, Urania). The area which served for initial practice was the Elba Island in search of metalliferous sands, in order to determine their thickness and heavy metal content.

At the end of the '80s, the new Geological Mapping of Italy at the 1:50,000 scale (CARG Project) was started. The coastline was not considered any longer a surveying limit and geological surveying and cartography was extended to the continental shelf, also thanks to the fast development of acquisition techniques. The approach adopted by the Geological Survey of Italy requires remote sensing data (multibeam, sidescan sonar, seismics) as well as groundtruthing (samplings, ROV, scuba diving). A database collecting all kind of information has also been developed.

Geological mapping of submerged areas has also been realized at the 1:250,000 scale for the Adriatic Sea. It provides a comprehensive representation of the units covering the seafloor complemented by a geological map of the units underlying the present sedimentary succession, which allows to identify deep structures.

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The crystalline basement of the Alps with particular reference to the Italian side: an unpublished report for CNRN by Angelo Bianchi and Giambattista Dal Piaz, 1958

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Keywords: Pre-Triassic crystalline basement, Alps, unpublished report, CNRN, Angelo Bianchi, Giambattista D

The National Committee for Nuclear Research (CNRN) was established in 1952 to promote and develop Italian research in nuclear science and technology, later incorporated into CNEN (1960) and ENEA (1982). CNRN created the Frascati synchrotron and the nuclear research centers of Ispra and Casaccia. One of its tasks was the survey for U-bearing ore in Italy, run by the Geology and Mining Division chaired by Felice Ippolito. As regards the Alps, the scientific guidelines for the planned survey were entrusted to Angelo Bianchi and Giambattista Dal Piaz, with a view to providing an updated study of the pre-Triassic crystalline basement. Research dealt with the following, main topics: i) recognition of stratigraphic and petrographic features, and lithological successions within tectonic and metamorphic basement units; ii) identification of sedimentary and igneous protoliths; iii) analysis of rock-types, accessory minerals, metamorphic grade and polymetamorphic (if any) processes in each unit; iv) structural patterns and deformation features; v) primary relations between metaintrusives and metasediments; vi) geological evolution of each tectonic unit as concerning erosion and sedimentation, stratigraphic gaps and unconformities, succession of magmatic, metamorphic and orogenic cycles; vii) modern views on the stack of nappes and their prealpine history; viii) along- and across-belt correlations. The first stage of the study resulted in the confidential report to CNRN, titled "*Il Cristallino Antico delle Alpi, con particolare riguardo al versante italiano – Relazione preliminare riservata, Padova 1958*", a typed memoir of 229 pages, a working tool devoid of references, including a synthetic geological map at 1:1,000,000 scale. A number of mimeographed copies were subsequently distributed to the scientific and technical staff of the project, as well as to academics and students working on the Alpine crystalline basement. From its appearance in 1958 to the beginning of the eighties this memoir was the reference work for people addressing such issues as igneous and metamorphic features, as well as structure and overall lithology of the main basement units, all along the inner side of the Alps from Verampio dome - the core of the collisional belt - to the capping Dent Blanche nappe, from the Tauern window to the eastern Austroalpine nappes, and the Southalpine basement: a "bible" for some young "*geologi del cristallino*" (hard-rock geologists) of those (unfortunately) long gone years.

The 1906 Ustica earthquake, a case of civil protection of the last century

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Keywords: Earthquake, Ustica, 1906

In 1906, from March 18 to April 6, the island of Ustica was hit by a sequence of small and medium-intensity earthquakes that caused injuries to the poor dwellings and panic among the population.

The seismic sequences consisted of about 50 shocks, with maximum intensity of VI degree on the Mercalli Scale (Martinelli, 1910; Foresta Martin et al., 2011). According to the Parametric Catalog of Italian Earthquakes (Rovida et al., 2011) the energy released by the main shock of the sequence corresponds to a Richter magnitude of 4.72 ± 0.34. Despite the light magnitude of the earthquakes, officials of Palermo Civil Engineering Office reported extensive damage to the village of Ustica, concentrated in the eastern part of the island, where they recorded slumps and injuries to the buildings (Foresta Martin et al., 2011).

One of the most contradictory aspect of this phenomenon consisted in the fact that the earthquakes were recorded only by a small seismoscope placed in the island's meteorological station (Semaforo of Monte Guardia Grande), while no other instruments in nearby Palermo or in other parts of Italy were able to detect these events, probably due to the fact that the hypocenters were very superficial (Alfani 1906).

A scientific mission formed by professors T. Zona, G. Di Stefano and M. Gemmellaro, from the University of Palermo, made a careful survey of the Island, not only in the town, but also in the countryside, around the coast and in some caves, but without detecting dislocations of land or faults (Foresta Martin et al., 2011).

Fearing the arrival of a strong destructive shock, the Prefect of Palermo ordered the evacuation of about 1,000 people and 600 prisoners confined in the Island. All that people was transported to Palermo on board civil and military ships. This was the first case of evacuation of a town of the young Italian State. The event was widely reported nationwide and internationally with comments sometimes alarmist and exaggerated. Some volcanologists feared the reactivation of the old and dormant volcano usticese and destruction of the island (Alfani, 1906). When the emergency ended, while the displaced inhabitants were returning in the island impoverished and deprived of food and other basic necessities, the King of Italy Vittorio Emanuele III and Queen Elena, who were on an official visit to Palermo, unexpectedly landed on the tiny island, to comfort the residents and to offer economic support (Foresta Martin et al., 2011).

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Back to the future: Felice Ippolito, a forward-thinking Italian scientist of the XXth century

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Keywords: history of geology, nuclear energy, engineering geology.

Felice Ippolito was born in Naples in 1915. After last year's centennial celebrated in Rome by the Italian Nuclear Association's, the 88th Congress of the Italian Geological Society held in Ippolito's hometown (almost sixty years after the Naples Congress he himself organized in 1957 as President of the Society) offers a good opportunity to commemorate him. He can in fact be considered a member of the geological community, as geology is a thread woven through various phases of his life, from his teachers through his career.

He studied the works of Leopoldo Pilla, professor of mineralogy and geology at Pisa, and one of the founders of Italian geology. Felice was also one of the pupils of Giuseppe De Lorenzo, who had a deep knowledge of the geology of southern Italy, and then of Alfred Rittmann, whom many consider the founder of modern volcanology. In Naples with Rittmann, Ippolito studied the Phlegraean Fields, Ischia and the other Campania islands, Roccamonfina, and Vesuvian lava. In one of his books (1988), Ippolito points to him as one of the teachers closest to his own scientific path. Rittmann, as Ippolito himself stressed, played an essential role in Germany in the first attempts to go beyond Alfred Wegener's theories and in introducing the modern theory of plate tectonics, on the basis of petrographic and magmatological observations. Ippolito also engaged the ideas of Benedetto Croce, to whose work he devoted an essay (1985) and in which he focused on Croce's views of the logical and heuristic value of the natural sciences, aiming to go beyond the opposition between scientific and humanistic culture.

But the principal reason why we remember Felice Ippolito was his role from the late 1940s in Italy's energy policy, through both his work in the field of hydroelectric energy and his research into peaceful uses of nuclear energy, as he aimed to achieve Italy's energy independence (Curli, 2000). Thus he took interest in Italian uranium research and began collaborating with Edoardo Amaldi, then already a world-famous physicist, with whom Ippolito founded CNEN (National Committee for Nuclear Energy), of which from 1960 he was general secretary starting. Together with other celebrated scientists, he promoted the development of nuclear energy in Italy, managing to place the country in the vanguard of such developments; these efforts were ultimately stopped by political pressures and economic interests opposing the development of nuclear energy, culminating in Ippolito's arrest and trial, which brought to an end to an opportunity for growth for Italy (Pivato, 2011).

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The Geology and the Roman catacombs. Michele Stefano De Rossi (1834-1898), a geologist inventor

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Keywords: Michele Stefano De Rossi, "iconographic machine", catacombs, Rome.

During several investigations and studies on the presence of underground cavities in the Rome area in the last 20-25 years, I came across in the documents of a geologist, who lived in the XIX century, that pushed me to know his life and his work, especially with reference to the fact that in some of his works on the catacombs was reported that he had invented a "icnographic and orthographic machine to detect plants and levels.": Michael Stefano De Rossi (1834-1898) .

From the research on this geologist, and from reading his texts, it was emerged a figure of scientist who has contributed substantially and with a decidedly "illuministic approach", to debunk many “legends" on the Underground Rome and, for the first time, It has supported the importance of the geological context for understanding the reality of the Roman underground networks.

The research also allowed a reconstruction of the relationship between geology and archaeological research by the catacomb from seventeenth to the twentieth century.

The Author is known primarily as a geophysicist, but the work of Michael Stefano which is examined here is its contribution to the study of the geology of the catacombs that has developed accompanying the older brother Giovanni Battista, already known archaeologist, on numerous expeditions in the Roman catacombs.

In particular Michele Stefano was the first to examine the catacombs in a geological context and also, according to this approach, emphasizing the importance of studying the planimetry and altimetry of the catacombs networks and showing these absences in the studies of previous centuries, whose maps are incorrect and inaccurate.

To overcome the difficulties of performing underground surveying, given the obvious adverse environmental conditions, Michele Stefano design his "icnographic machine" with the help of mechanical Ermanno Brassart (best known as a designer and manufacturer of seismic instruments).

On May 6th of 1860 Michael Stefano has a communication from the Pontifical Accademy of “Nuovi Lincei” entitled "Amplitude of the Roman catacombs and a icnografic and orthographic machine to detect plants and levels" (M.S. De Rossi, 1860). In that communication, Michele Stefano describes meticulously the mechanics and the use of his “machine” for 15 pages by referring to a table in which are drawn the various parts of the equipment.

The “machine” of Michael Stefano is rewarded with a medal at the Universal Exhibition of London of 1862 and to the International Exhibition in Paris in 1867; with such a machine the author prepared a map of the catacomb of Callisto accompanied by geological sections, rewarded at the Exhibition in Dublin in 1866.

For a better analysis and vision of such equipment, we tried, on the basis of his instructions, to reconstruct the various parts in a 3D processing software.

De Rossi M. S. 1860. Dell'ampiezza delle romane catacombe e d'una macchina icnografica ed ortografica per rilevarne le piante e i livelli, Atti dell'Accademia Pontificia de' Nuovi Lincei. Sessione VI del 6 Maggio 1860

De Rossi G.B. 1864. La Roma Sotterranea Cristiana descritta e illustrata, 3 voll., Stamperia Vaticana, 1864.

De Rossi M.S. 1864. Analisi geologica ed architettonica in La Roma Sotterranea Cristiana descritta e illustrata, 3 voll., 1864.

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The contribution by the Lombard researchers to the development of geological mapping during the XIX Century from Brocchi to Taramelli

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Keywords: History of Geology, Italian Geologists, Geological Mapping.

The purpose of this paper, to be presented as a poster, is to show the contribution given, during the XIX century, from the Lombard researchers in order to carry out geological maps able to support the comparison with those realized by foreign geologists (as L. von Buch, F. R. von Hauer., H. T. de La Beche and others). Indeed still in the first quarter of the century in Italy the geological mapping was scarce and inadequate in order to give reliable information, surely owing to lack of suitable mapping proceedings. But it is really in this time the Lombard geology becomes animated by strong personalities as G. B. Brocchi (Physical map of Roman soil, 1820) and S. Breislak (Geological description of the Milan province, 1822), inclined to work on the field because their public offices (and in the same conditions is also G. Curioni with the Geological map of the Lombard provinces, 1877), all skilled in the mining researches, but also scrupulous observers of the soil features.

On the basis of the experiences matured in contact with the French, Swiss and Austrian geologists, one must remember the researches and monographs made by G. Omboni (Sequences of sedimentary rocks in Lombardy, 1855; About the Italian geological conditions, 1856; Geology of Italy, 1866-69), the maps made by E. Cornalia (Geological map of the South Tyrol, 1847; Geological map of Istria, 1850), C. F. Parona (Geological map of the Oltrepo Pavese, 1879) and others. Lastly the best contribution to the Lombard and Italian geological mapping is that given by T. Taramelli, loyal disciple of A. Stoppani, indefatigable surveyor of the Carnic and Julian Alpes of which he leaved very extraordinary documents (Geological map of the Istrian Margraviate, 1873; Geological map of Friuli, 1881, and many others). The remarkable level reached by the Italian geological mapping will be esteemed, during the second International Geological Congress in Bologna (1881), by means also of the first edition of the official great Map of Italy made by the Royal Italian Geological Survey.

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Early oil explorations and production in the Maiella-Tocco Casauria oil province across the 19^{th} and 20^{th} Centuries

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Keywords: Petroleum History, Heavy oils and bitumen, Abruzzo, Maiella, Tocco Casauria.

Our research, supported by the collation of heterogeneous sources from national archives and libraries, addresses the geological investigations and entrepreneurial activities that interested the Abruzzo region in the area between the Apennine chain front (Tocco Casauria oil spring district), and the Maiella Mountain (where oil seepages occur over extended portions of land), across the ‘800 and ‘900.

Our aim was to outline and frame in the historical contest the stories of the petroleum geologists that firstly assessed the area, tried to decipher the mechanism of HCs accumulation and, finally, advised where to place - what is supposed to be - the first oil well drilled with mechanical means in Italy, in 1864.

This area was a well-known petroleum province since centuries: archaeologists found bitumen mines dating back to the Roman age, and medieval chronicles mention the trade of *oleum petronicum* with travellers from continental Europe. The abundant surface evidences triggered new interest in the 2^{nd} half of 19^{th} century, when *wildcatters*, national and foreign entrepreneurs started to invest in the region, developing old and new oil fields and mines: every character involved in this early stage had a role in the - slow and not linear - development and rationalization of the modern oil industry in Italy.

In early 1860s, after centuries in which oil mining in Abruzzo was an unchanged craft activity, new businessmen purchased exploration rights of several lots; but, doubts and uncertainty were still preventing them to undertake expensive drilling operations. The need to unveil the prospectivity of finding HCs and to collect scientific evidences on their quantity/localization in the subsurface, convinced these early entrepreneurs to involve geologists from the academia, such as G. Capellini (1833–1922) and A. Stoppani (1824–1891): few years after this farsighted intuition the area developed into what became, for almost 90 years, the second larger oil district in the Italy.

At beginning of 20^{th} century, a complex mining exploitation system developed along the Maiella NW flank (with tunnels, pits and a system of cableways/mine carts), arriving to cover about 40% of Italian national production and able to export bitumen/asphalts products all over the world. In parallel, a new period of modern exploration was initiated, with the drilling of deep wells, such as Abbateggio-1 (1927), Lavino-1 (1934), Alanno-1 (1937), and the drilling of several development wells in the Tocco Casauria oil field (1934-1943).

The archive findings and the still visible surface evidences in the area (abandoned mines, pits, quarries, facilities), are clear witnessing of the cultural richness and historical relevance of the Oil&Gas industry in Abruzzo, from both geological and technological point of view: this history appear as dense of learning experiences and represents an example of a successful scientific and industrial effort, that contributed to the development of the whole region.

The Edition Open Sources Project. Towards a critical edition of Antonio Vallisneri's manuscript *Primi Itineris Specimen* (1705)

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Keywords: History of Geology, Digital Humanities, Critical Editions, Edition Open Sources, XVII Century, XVIII Century.

EOS (www.edition-open-sources.org) is a pioneering project in the field of scholarly publishing, which aims to edit and publish open access, peer reviewed critical editions of primary sources in the history of science. As EOS Postdoctoral Fellow, I am working towards an edition of Antonio Vallisneri's *Primi Itineris per Montes Specimen Physico-Medicum* (Vallisneri, 1705): a manuscript containing a wide array of geological, biological, historical, and technical data, including two maps of the Tuscan region of Garfagnana. Vallisneri, a major figure of his time in the field of medical and natural sciences (Generali, 2007; Luzzini, 2008, 2011a, 2011b, 2013), wrote this report after a journey he made in the Northern Apennines. This experience allowed him to support his theory on the meteoric origin of springs with conclusive empirical information, exposed in the *Lezione Accademica intorno all'Origine delle Fontane* (Vallisneri, 1715).

The *Primi Itineris Specimen* can be considered by all means as a precious document for the history of science in Europe. As far as we know, it is one of the earliest and most well-documented attempts to define an experimental and systematic approach to naturalistic explorations, offering a valuable insight into the requirements, criteria, and purposes to which field research should conform, according to a natural philosopher of the early eighteenth century. Once published in the EOS series, the manuscript will give a significant contribution in showing how experimental data and theories in the early modern period interacted and shaped the development of several main scientific, philosophical, social, and religious debates: the discovering of deep-time, the comprehension of geological phenomena, the perception of man's place in nature, the search for new therapeutics, the tormented – though fertile and charming – relationship between science and religion.

The edition will be complemented by an interactive map of the itinerary, with access to different data such as pictures, bibliographical references and sources, and links to related websites.

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Michele Gortani – scientist, humanist and statesman

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Keywords: geology, applied geology, geography.

After five generations only the most imposing figures emerge from the mists of the past. Michele Gortani (1883-1966) belonged to another era, one vastly different from today's – but any examination of what he did and what he wrote reveals a truly modern spirit and shows him as a precursor. Michele Gortani's method of thought and the originality of scientific discoveries are grounded in his humanistic training. He chose as his personal motto after the Enlightenment Veritati libere servio and indeed his scientific lineage traces back to Lazzaro Spallanzani and Antonio Stoppani. His education in the natural sciences was essentially in the field, branching out into geology, geography, botany . His scientific output consists of 329 works including a number of books, of which 250 were in the field of geology. This total does not include the very many reports, reviews and journals. The world in which Gortani the scientist moved was international. His peers were the geologists of Austria, Germany, France and the United States. Early in the 20th century his work on dating in the Carnic Alps "had an impact like a bomb exploding" according to Austrian geologists. A shattering resonance also followed his violent quarrel with the noted French geologist Pierre Termier who after a fleeting visit too rashly sought to apply the theory of nappes, then valid for the Swiss Alps, to the Eastern Alps. Through his international contacts Michele Gortani came to respect other cultures while maintaining the most steadfast love of his own homeland. The breadth of his cultural vision thus put him in a position to help the Carnic people when their territory was invaded by enemy forces in two world wars. Three works of his – Exogenous Geology, Compendium of Geology and an Atlas of the Landscapes were highly innovative. He applied geology to the protection of soils, dams and major infrastructures, to coal and hydrocarbons prospection, and even to military geology. His other areas of expertise included speleology, toponymy and ethnology. He regularly had to fight against the commercialisation of the public domain such as the occupation of riverbeds and active alluvial cones. He felt compassion equally for human suffering and for nature's ruination. This work involved him in the cultural development of his people through educational, social and legislative initiatives. He established the Carnic Museum of Popular Art and founded schools. His published Guides of Carnia and Canale del Ferro are rich in cultural references and show respect for identities and minorities. Michele Gortani was for many decades, since 1913, the purest elected representative of the Carnic people, however, during the fascist period he was a professor at Bologna. From 1946 to 1948 was member of the Constituent Assembly and brought into our Constitution measures for the protection of mountains and the promotion of handicrafts; later be became a Senator.

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Rediscovery of Curioni's slab: the oldest scientific description of vertebrate footprints from Italy

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Keywords: Curioni, oldest description, vertebrate footprints

Vertebrate ichnology in Italy fully developed rather recently, especially starting from the 70's of the last century. However, fossil footprints from Italian continental successions were known since the 19th century. The first scientific note, after a short report on the same material by Geinitz (1869), was published by Curioni (1870), who described and figured a small slab with tetrapod tracks from the lower Permian strata of Lombardy (upper Trompia Valley, Alps of Brescia, Collio Formation), found by the private collector Don Giovanni Bruni. Subsequent publications always referred to that description, but the original specimen was never restudied, due to the absence of references about the repository in Curioni (1870). The original specimen belongs to the prestigious collection Curioni (donated by Curioni to the "Regio Ufficio Geologico" in the year 1877) and is nowadays located in the Italian National Institute for Environmental Protection and Research (ISPRA) of Rome (Repository number 4426; see link below).

It was newly analysed with the most advanced ichnological methods and approaches (i.e. digital photogrammetry). The study definitively confirmed the attribution of the pes-manus couple and the single manual imprint to the ichnogenus *Amphisauropus*, tracks probably produced by seymouriamorph reptiliomorphs. Other footprints on the same surface were instead assigned to *Dromopus*, tracks probably left by diapsid reptiles or bolosaurid parareptiles. Thus the work by Curioni (1870) represents in all respects the first description of vertebrate footprints from Italy and the first worldwide on material attributable to *Amphisauropus* (before Geinitz & Deichmüller, 1882) and one of the earliest on material referable to *Dromopus*. The studied slab could also represent the earliest finding of *Amphisauropus*, but presently we only know a very approximate time range for Don Bruni's discovery (between 1856, starting date of the field work and 1869, date of first reference to this material). The new description of Curioni's slab constitutes a very significant contribution to the history of vertebrate ichnology in Italy and in the world. The case study highlights once again the importance of communication of the institutions that preserve fossil material and of proper repositories for the preservation of geo-palaeontologic heritage, allowing further and advanced analyses of original specimens even after almost 150 years from the last study.

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Geinitz H.B. & Deichmüller J.V. 1882. Die Saurier der unteren Dyas von Sachsen. Palaeontographica, 29, 1-4.

http://www.isprambiente.gov.it/it/museo/collezioni/collezioni-paleontologiche/paleo-reperti/impronta-di-orme-di-rettile

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The 'Carta Geologica delle Alpi Occidentali' (Geological Map of the Western Alps) of the Regio Ufficio Geologico d'Italia at the 1:400.000 scale

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Keywords: History of Geology, Carta Geologica delle Alpi Occidentali, R. Ufficio Geologico d'Italia.

Published in 1908, the Carta Geologica delle Alpi Occidentali at the 1:400.000 scale represents one of the most innovative product of the Regio Ufficio Geologico d'Italia, and it is even now a geological map of unquestionable validity.

Based on official and unpublished documents, papers, geological maps and personal field booklet of the R. Ufficio personnel, this contribution described the history of that map, from the first field surveys to its publication.

This map is derived from new and extensive field studies performed in the Western Alps from 1888 to 1906 by S. Franchi, E. Mattirolo, V. Novarese, A. Stella, and D. Zaccagna (personnel of the R. Ufficio) for the geological map of Italy at the 1:100.000 scale. The first reference on the Carta Geologica delle Alpi Occidentali appears in the early 1900s, both in the frame of a collaboration with the French geological survey and with the scope to draw a map reporting the results of the Italian surveys. In fact, the relevance of the field surveys of the R. Ufficio personnel was evident from the beginning of the geological map project when Zaccagna and Mattirolo first identified from the Maritime to the Cottian Alps large extensions of Carboniferous, Permian and Triassic rocks also in most of those successions previously reported as Jurassic by Sismonda (1866) or Pre-Paleozoic by Gastaldi et al. (1879, in Campanino & Polino 2002).

However, a first partial edition of the considered map can be already recognized in the "Carta Geologica delle Alpi Cozie Italiane" drawn by Franchi in 1898 to point emphasis on his striking discovery of the Mesozoic age of the "Calcescisti con Pietre Verdi" zone (conversely thought as Pre-Paleozoic by Gastaldi et al., 1879, in Campanino & Polino 2002).

Fundamental aspects of the Carta Geologica delle Alpi Occidentali are certainly represented by the detailed mapping of the rocks of the crystalline massifs and, as introduced above, the attribution to the Mesozoic age of the "Calcescisti con Pietre Verdi" zone. However, this latter interpretation gave rise to a fierce debate inside the R. Ufficio, because Zaccagna and Mattirolo strenuously supported a pre-Carboniferous age for those rocks (as reported also on the published map).

The importance and the innovative character of this map was clearly recognized by Argand, who defined it as "l'inestimable document moderne" of the western Alps (Argand, 1923).

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1867: Early geological knowledge from the Italian provinces

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Keywords: History of Geology, Geological map.

Immediately after the unification of Italy, in March 1861, due to the initiative of Quintino Sella, a project started that deepened the geological knowledge of the country through the geological mapping. The Ministry of Agriculture, Industry and Trade (MAIC), from which the Corps of Mines depended, in July 1861 issued a Royal Decree setting up an Advisory Council for the realization of the geological map. In April 1866, the MAIC established a geological section on the Council of Mines, prior to the founding of the Royal Geological Committee, in December 1867, and of the R. Geological Survey, in June 1873 (Pantaloni, 2014). Cocchi, Meneghini and Scarabelli chaired the geological section.

Igino Cocchi was convinced that an institutional structure could revive the great tradition of the Italian geological studies (Corsi, 1982). He was also conscious that Italy was the only major European country which lacked a geological map.

These expectations were concretized for the Universal Exhibition in Paris in 1867, in which the Italian government, on behalf of the MAIC, wanted to present the state of geological knowledge of the country; the latter provided with a geological map and a volume with statistical information concerning Italy (Maestri, 1867).

A collection of geological information started through the involvement of the Prefectures that, in turn, requested scientific report to the different Technical Lyceum, or to the well-known local scientists. Differently, for regions as Sardinia, Liguria and the Papal State, the already existing geological maps or scientific papers were used.

During the Paris Exposition, Cocchi presented a geologic map of Central and Northern Italy at 1:600.000 scale.

In the archive of the Geological Survey of Italy, preserved in the ISPRA Library, we founded all the original manuscripts, as well as geological published or unpublished maps of the most important authors.

This material, cataloged, transcribed, studied and in part digitized, allowed us to reconstruct the state of geological knowledge of Italy a few years after its unification. Such a study highlights dramatic differences among the various Italian provinces, with main interest varying from the pure academic study to the applied knowledge for geological resources (e.g. mines, quarry, etc).

Thus, as a whole, the analysis properly stress the enormous cultural and economic interests related to the development of geosciences in Italy.

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Use of cartography and historical sources in the study of human settlements changes related to the evolution of the territory: the Tiber River medium valley (Central Italy) case history

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Keywords: cartography, human settlements, Tiber River medium valley, Central Italy.

The results of this study aimed at understanding territorial transformation are explained through the key role of the analysis of historical maps and historical sources. The research focused on an area of the Tiber River medium Valley between Riano Flaminio and Nazzano Romano, where many settlements flourished in ancient times. The first step of the study was the analysis of the geological evolution and the current geomorphological setting. The second step concerned the identification and the study of the locations of ancient settlements, and the following creation of a GIS database. The third step involved the filling out a special form containing data on single settlements and the existence of geological "signs" i.e. (fumarolic events, hydrothermal springs, etc.). Natural phenomena and geologic events were then mutually linked, highlighting the elements of concatenation through which the settlements themselves assumed aspects, role and function we can still denote today. In this context, the analysis of historical maps has been a very useful tool for understanding the territory's transformations, especially since the XVI century up to the great urban transformations occurred till the mid-twentieth century.

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The contribution to the geological knowledge of Tripolitania and Cyrenaic regions (Libya N-Africa): the first Italian expedition between 1910 and 1914

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Keywords: History of Geology, Libya, Geological exploration, mineral resources.

Between 1910 and 1914 the Italian government organized a number of scientific expeditions in Tripolitania and Cyrenaica to explore their territory. Some outstanding Italian geologists take part to the missions.

The first preliminary mission to Libya, led by M. Sforza and I. Sanfilippo, lasted from June to August 1910. The research-team investigated the possible occurrence of sulphur-bearing deposits in the Sirte desert area. The expedition was followed in 1911 by the "Missione Mineralogica Italiana Sanfilippo-Sforza" during which the five Italian members were arrested because considered spies after the Italian declaration of war on Turkey. During the mission several mineral, rock and fossil specimens were collected in Tripolitania and Fezzan regions. Rocks were studied by E. Artini while the rich Maastrichtian fossil fauna (bivalves, echinids, gastropods and cephalopods) were analysed by the palaeontologists G. Di Stefano and G. Checchia Rispoli.

In 1912, after the claims of Italy over Libya, a new expedition, leaded by S. Franchi, geologist of the R. Geological Survey of Italy, was carried out to examine the geological and hydrological characters of Libya. In 1913 other geologists, such as F. Parona and C. Crema, joined the research-team confirming the occurrence of a well-developed and fossil-rich Maastrichtian phosphatic horizon.

In 1913 started the "L. Franchetti mission", during which several geotechnical, mineralogical and hydrographical data of the Gebel plateau were collected. In 1914 S. Franchi and P. Zuffardi explored the central sector of Tripolitania, confirming the absolute lack of phosphate deposits in the examined territories. In the same year D. Zaccagna, a gifted geologist of the R. Geological Survey of Italy, made stratigraphical analyses in the area between Garian and Ghadames, recognizing the "Wealdian strata" (Lower Cretaceous) and a fossil-bearing Maastrichtian limestone.

The material collected in these scientific missions is nowadays scrupulously preserved at the Geological Survey of Italy in Rome and consists of geological maps and documentary evidences. The palaeontological collection was split and is now preserved at the Regional Natural Sciences Museum in Turin and at the Paleontological Museum of the Sapienza University in Rome. The aim of this research is therefore to analyse all the documents and rock samples to reconstruct all the field activities carried out by the Italian geologists, emphasizing their huge and extremely detailed contribution to the geological knowledge of these regions.

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Leonardo da Vinci: Cartographer

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Keywords: Leonardo da Vinci, cartography, geology, maps, topography.

The artist Leonardo da Vinci (1452–1519) was also a geologist and cartographer. He was an ardent observer of the Earth's topography, depicting it precisely in his paintings and, by using surveying instruments he developed, produced a variety of maps which were extraordinarily accurate and precursors to modern ones.

While in the service of Ludovico Sforza in Milan, da Vinci made many maps for civic as well as defensive purposes. He was familiar with the simple land-register plans, which he found at the municipal council. Then, using his artistic skill, drew maps producing both aerial and perspective views.

After leaving Milan in 1499 he consulted with the Venetians, who were concerned about a Turkish attack. He suggested artificial inundation of the Isonzo valley in Friuli and drew a small sketch map of the area.

One of his most audacious assignments was to advise Florence on its plans to divert the Arno River away from Pisa, its enemy. Leonardo drew a series of reference maps. However, long before this military assignment, he drew maps envisioning ways to change the course of the Arno and open Florence to the sea.

Leonardo's maps were remarkable not only for their geographic accuracy, but because they anticipated modern day map-making by his dark shading of mountains and careful attention to rivers, lakes, valleys and towns. His alpine maps capture the geology of the area so precisely that rock types as well as mountain peaks can be identified.

In 1502 Leonardo, as military architect and engineer, worked for Cesare Borgia, whose goal was to conquer all of Romagna (north-central Italy). Da Vinci became chief inspector of military fortifications thus, traveling freely throughout the embattled region to investigate and evaluate. He looked not only at structures, but ports, waterways, trails and natural formations which could be useful for, or a hindrance to Borgia's military objectives.

As da Vinci travelled through Romagna, he made a series of maps to be used for military purposes. They included geological and topographical information, vital for developing battle plans. Many of them survive today, including geographic sketches of the entire Piombino coastline, *The Arno River and its Watersheds* with its extraordinary aerial perspective, showing the river, with its vein-like tributaries and intricate drainage patterns curving its way through the mountains near Pisa down to the marchlands of the Chiana valley and one of the *City of Imola*. The unprecedented accuracy of this map, based on his odometer readings, was critical, as Imola was an important military base for Borgia.

In 1508 he sketched an octant projection and in 1514 made an octant world map, the first known example of its time. His lifelong map production had an unexpected result: they established da Vinci as a master of cartography, as nothing so precise had ever before been produced.

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Old geological maps of the Dolomites stored in the library of the Department of Geoscience, University of Padova

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Keywords: Geological map, Dolomites, Padova Geosciences Department, old library.

An Ancient tradition on geological research brougth the library of the Geoscience Department at Padova University to become a reference for old geological books and maps. Although one of the main inheritances was surely the books and maps of Achille De Zigno, the presence in this University of naturalists as Antonio Vallisneri, Tommaso Antonio Catullo, Giovanni Omboni, and all the Dal Piaz ancestry, made the incredible collection of this ancient library possible.

The "cartoteca" (map collection) together with the "Old section" are a really important body of the library itself and frequently make interesting discoveries possible, as for the recent recovery of Leopold de Buch's map of the trentino region, originally published in 1822. This *Esquisse d'une Carte Geologique de la partie orientale du trentino*, one of the first geological maps of the Dolomites, was offered to Adelaide De Zigno around the middle of the XIX century.

Later on, Wilhelm Fuchs published in the 1844 his *Geognostische Karte*, together with a book and many geological cross-sections. This geological map was followed by many others, also present in the Library, as those of von Morlot (1847); Franz Foetterle (1856, with the revision in the 1838); Ferdinand von Richthofen (1859) and Hauer (1867). Among these, one really important map is the *Geologische Ubersichtkarte des Tirolisch-Venetianischen Hochlandes zwischen Etsch und Piave* by Edmund von Mojsisovics (1878).

Among italian authors, after the geological map made by Cornalia (1848), that used as base von Buch's map, one that deserves attention is the work of Taramelli: Carta Geologica della Provincia di Belluno, with its explanatory notes (note illustrative), published in 1881.

Almost all maps stored in the Library were pasted on canvas for the aim and necessity to use these maps in the field. This preparation preserved them from degradation.

As these maps were not all realized from precise field observations but rather represented a synthesis of the geological thought of the authors at the time, they are a really important source of information for the history of geological sciences.

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The skeletons of Ajax, Antaeus and Orontes: misinterpretation of vertebrate remains as a proof of mythological Giants

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Keywords: Quaternary vertebrates, Cuvier, Cyclops, insular dwarfism, comparative anatomy, mythology.

The myth of Giants as first inhabitants of countries and entire nations is a common legend shared by several cultures and religions. In the present work we highlight as one of the factors that fueled the myth was, most likely, the discovery of large vertebrate bones (in large part Cenozoic) in sedimentary deposits or in karstic caves: osteological material initially interpreted exactly as the extraordinary remains of titanic men. Thus, large skeletons found since ancient times, largely referable to elephants, rhinos, bears, hippos, cetaceans and other large vertebrates, were interpreted by authoritative writers and poets such as Strabo, Philostratus, Pliny, Homer, Saint Augustine and Boccaccio (just to name a few) as the bodies of mythological giants Antaeus, Ilio son of Hercules, Orestes, Ajax, Orontes, Pallas, Cyclops, Lestrigons and Lotus Eaters. As for the myth of the Great Flood, even the hypothesis of the giants found a convenient literal confirmation in the Holy Scriptures, definitely going to support and enhance the legend. In the Italian scene, until the end of eighteenth century several authors were firmly convinced that entire nations of giants really existed in the past, which, before being destroyed by the Great Flood, represented the first populations of many Mediterranean islands (including Sicily and Sardinia). One of the first interpretive 'revolutions' takes place in the first half of the eighteenth century with the study of the English physician Hans Sloane, that, in advance also on Cuvier studies, applied the rudiments of comparative anatomy to prove that the bones belonged to large cetaceans or land quadrupeds. According to the English physician, after a careful and comparative study, would have resulted quite impossible to confuse this osteological material with human bones. The work by Sloane had a great impact on the Italian scene, and the interpretation as bones of Giants was gradually fading until it disappears. However, some sacs of resistance persisted incredibly in Italy up to mid-nineteenth century.

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Wheat prices and the 1815 colossal eruption of Mount Tambora: tracing the global food crisis thanks to a superbly preserved archive in Northern Italy

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Keywords: Tambora Eruption, Climate change, cereal prices, Little Ice Age, Dalton Minimum.

In April 1815, Indonesia's Mount Tambora exploded in a colossal Plinian eruption, the largest in recorded history, with titanic pyroclastic flows and caldera collapse. The eruption sent a stupefying 160 billion cubic meters of ejecta skyward, with explosions heard on Sumatra, some 2600 km away. About 11,000 people died immediately as a result of incandescent ash falls, pyroclastic flows and induced tsunami, with an estimated 60,000 falling to associated disease and famine. The epochal eruption of Tambora was to have a marked impact in global climate. This year marks the 200th anniversary of the "year without a summer" in the Northern Hemisphere. A thick veil of sulfur dioxide and volcanic dust was projected into the stratosphere, reducing solar radiation and causing pronounced cooling in 1816 and following years, an effect that was aggravated by the fact that Earth was in the grip of the Little Ice Age. Cold temperatures and high precipitation led to agricultural catastrophe, particularly in eastern North America and Western Europe, where crop failure resulted in widespread famine. A superbly preserved original archive in the municipality of Rovereto (Northern Italy), allowed us to investigate the effects of this global event, even in small rural centers in northern Italy, stressing how an unexpected and instantaneous natural disaster (occurred approximately 15,000 km away), can decisively influence the socio-political and cultural structure of an entire community. Starting from August 13, 1744 up to December 28, 1824, the price for wheat sale was recorded on a weekly basis, in one of the largest centers for trade in the northeast of Italy of the time, crucial crossroads between the Serenissima kingdom and the Tyrol county, at the turn of the Po Valley and alpine areas. This incredible dataset (4830 price recordings) trace out the socio-economic trend for 80 years, in a period between the eighteenth and nineteenth centuries, in which some of the most severe food crisis and famine occurred. The obtained curve clearly shows how all major climatic and political crises (Napoleon's invasion of Trentino, annexation of Trentino to Bavaria) are clearly recorded by a positive spike in the price of cereals, although the one that had the most devastating effects, and which last longer, is the one linked to the eruption of Tambora volcano, and results well marked by the peak of 1816 and 1817.

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Tuscany: mineral resources mapping in the 18th century

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Keywords: Tuscany, Lorena age, mineral resources, mines, mapping, Mazzoni, Eegat, Targioni Tozzetti, Arduino.

At the beginning of the Lorena age in Tuscany, during the regency period, the first aim of the new Grand Duchy was determining the potentiality of the economic resources (agriculture, industry, raw materials). Franz Stephan von Lothringen appointed as regent in Tuscany Emmanuel Nay of Richecourt.

In the 18th century in Tuscany some famous scientists such as Pier Antonio Micheli, Giovanni Arduino and Giovanni Targioni Tozzetti were active. Targioni wrote to the Count of Richecourt a “Dissertazione del Dottor Giovanni Targioni sopra l’utilità che si può sperare dalle miniere della Toscana”, dated 1743.

Probably after this hint, some tasks were assigned to technicians to execute surveys and cartographic representation of the mines (active or not) and their surroundings.

In the State Archives of Florence in the “Miscellanea di piante” section some maps of the regency period are preserved. These maps have been realized by Carlo Maria Mazzoni, a Tuscany engineer, and Francesco Antonio Eegat, a German speaking technician.

We have analysed 4 maps produced in 1766 by Carlo Mazzoni in Northern Tuscany: “Pianta topografica ed altimetrica minerale della Montagna Acuti e de’ suoi aggiacenti nel Capitanato di Pietrasanta”; “Pianta topografica ed altimetrica minerale della Montagna Gabbari e de’ suoi aggiacenti nel Capitanato di Pietrasanta”; “Pianta topografica ed altimetrica minerale della Montagna di Corchia e per alcuni monti a quella aggiacenti nel Capitanato di Pietrasanta e nel Comune di Terrinca situati”; “Pianta topografica ed altimetrica minerale della Montagna di Salioni e per alcuni monti a quella aggiacenti e situati nel Capitanato di Pietrasanta in Comune di Livigliani”.

In the period 1760-1765 Francesco Antonio Eegat realized 4 different maps in Southern Tuscany: “Carta del territorio compreso tra Montieri, Boccheggiano, Prata e Massa Marittima con l’indicazione dei giacimenti minerari antichi e moderni”; “Pianta e veduta della miniera e dell’opificio dell’allume situato nel territorio di Monterotondo Marittimo”; “Pianta e veduta della miniera e dell’opificio di rame situato nel territorio di Montecatini Val di Cecina”; “Pianta e veduta dei giacimenti minerari situati nel territorio di Querceto”.

All these 8 maps have been deeply studied form a “geographical” point of view but never analyzed from a geological-mining aspect. The aim of this work is to evaluate the features and characteristics of the maps and in detail the symbols. Another aim is to study the measure units, because these maps are “pre-metric” and use ancient units.

Beyond the simple territory representation, these maps use symbols to point out specific mine characters such as shafts, ore dumps, tunnels and ore veins. The ore seam symbol often contains information about thickness, direction and type of mineral (copper, lead, mercury).

At the end of this analysis it will be possible to understand the knowledge of mineral resources at that time and compare it with the subsequent development of mine activity in the same areas.

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The history of geology in Italy: origins, development and future

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Keywords: History of Geology, Historiography, 19th-20th century, Italy.

The aim of this paper is to present the development of the historical studies on different fields of the geological sciences in Italy in order to evaluate the state of the art of this discipline, to recognize its further interdisciplinary potential and to identify new topics and ways of research. A critical historical overview will be provided, from the early historiographical attempts in the 19th century until the researches undertaken by geologists and historians during the 20th century to date, within the Earth sciences and the history of science. The different methodological approaches, as well as the results of these studies, will be investigated and compared with other historiographical contexts, mainly in Europe. The role of the history of geology in the modern Italian society, with particular attention to the scientific and academic communities of Earth scientists and historians, will also be analyzed, in order to provide suggestions for more collaborations and interactions between the two cultures. The history of geology must be extremely open and flexible to new models and practices, because its topics are constantly changing and evolving. The future challenge will include the adoption of more specific skills and approaches both in human and natural sciences, as well as the use of technological tools in order to share data and improve the communication of the research work. Historical knowledge in Earth sciences can be also revaluated in applied contexts, in order to understand limits and problems of scientific theories and models.

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Raimondo Selli's (1916–1983) scientific works

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Keywords: History of Geology, Raimondo Selli.

Many chrono-events of a scientist's life may be useful to set in a wider frame his works. I tried to read all Selli's articles, monographs, edited books in a continuous time sequence, placing them in the context where and when they have been produced. The most relevant of them require first careful selection, then basic characterization by priorities, innovation, and validity. What is left today of Selli's legacy and scientific works over three decades after his premature death? His leading style and rigorous method is still aim and example for many, as shown by continuing international quotation of many of his fundamental papers in a great diversity of geologic fields. Based on his method and skills almost every thing he did and wrote is still alive, valid, correct, and in any instance useful. The two major institutions he had created in the 1960s in Bologna, the Geological Palaeontological Institute of the University, close to the old museum, and the CNR Marine Geology Laboratory are well competing in the world's geological arena. However, his immaterial legacy in terms of ideas, discoveries, and priorities set and documented in his many fundamental writings are the leading edge of his vital memory. Key words such as Messinian Stage (re-vitalized) and Messinian Salinity Crisis have been conceived and designated by Selli, and are increasingly quoted together with the author, also as a result of growing consensus upon his original interpretation. Each time anyone is asked to consider Neogene and Quaternary chronostratigraphic divisions, he will have to consult, discuss, and quote Selli's fundamental papers, weather associated or not with Ruggieri's and Cita's comments, as we are doing with Brocchi's and Lell's, because he gave birth and meaning to most of the present and future stages of this part of the Standard Stratigraphic Geologic Time Scale. Nobody engaged in the Mediterranean marine geology and plate tectonics should forget that most of the central Tyrrhenian oceanic crust is Pliocene in age after him, not early Miocene. Everybody today knows that before the event the great Vaiont rock slide was not to be foreseen, but, after Selli's assessment, it was to be expected, so that any new similar dam project in any part of the world needs to overcome in advance the simulation of a Vaiont test. Every time Italian or foreign scientists are doing research on geology, structure, stratigraphy, geological mapping, seismicity, engineering geology and land planning in any part of Southern Italy, Selli's monographs have to be considered, deeply studied, and quoted because he has introduced and named over half of the main geological formations, and, most important, he was the first to conceive a complete, consistent, unitary and synthetic structural interpretation of the whole wide area. Today in Naples, a city he loved so much, we shall touch this only very prominent part of his manifold scientific work.

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Geological lanscapes and manufacturing in Lombardy betweenthe 18th and 19 centuries: an increasingly close-knit interconnection

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Keywords: Geology, 18th and 19th centuries, Lombardy, travels, maps.

The study attempts to highlight, through an analysis of the largely unpublished writings of Ermenegildo Pini (1739-1825), Carlo Amoretti (1741-1816) and Giulio Curioni (1796-1878), the peculiarity of the close relationship that formed in Lombardy, unlike in any other of the italian states, between the birth and development of geology and that of the mining and manufacturing activities: a fine fabric that began to be woven under the first Habsburg domination, becoming denser in the Napoleonic era and even more so during the Restoration.

The analysis will begin with the work carried out by Pini and Amoretti, both in the Patriotic Society and the Council of Mines, geared to the safeguarding of the woodlands, the search for fossil fuels and the improvement of the smelting furnaces. It will then move on to describe the journeys undertaken for such purposes by the two naturalists, with the presentation of the maps, drawings and itineraries that accompanied reports on these journeys, and are still unpublished or little studied today.

From this perspective, the work will focus on the figure of Giulio Curioni and the dense fabric that he was able to weave by interconnecting his many excursions, the narrative of wich was often illustrated with drawings and cross-sections of rocks (which formed the basis for creating the well-known Geological map of the Lombard provinces, 1877), and the hegemonic role that he played in improving the techniques applied in the mining and manufacturing industries, especially that of iron.

Lastly, the work will propose the publication of some particularly significant unpublished writings in relation to the above.

SESSION S36

Geoethics: a new way of thinking and practicing geosciences

CONVENERS AND CHAIRPERSONS

Stefano Tinti (Università di Bologna)
Francesco De Pascale (Università della Calabria)
Sabina Di Franco (CNR-IIA Roma)
Alessandra Magagna (Università di Torino)
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The semiosis of the Anthropocene: the triangle "geology/geography – planet illness – society"

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Keywords: Anthropocene, geoethics, geography, Peirce, semiotic triangle.

This paper presents the formulation of a theoretical proposal which aims to reconcile, or better, to work together, two different approaches: geoethics and the semiotic tradition of Peirce (1839-1914), on the basis of some important affinities. Charles Sanders Peirce was a mathematician and philosopher known for his contributions to logic and epistemology; furthermore, he was the founder of pragmatism and modern semiotics.

The work will refer to geoethics, discipline that deals with the ethical, social and cultural implications of geological practice, at the intersection of Geosciences, Geography, Philosophy, Sociology and Economy (Peppoloni & Di Capua, 2012, 2015).

The proposal of this work is to try to explain the new processes of the Anthropocene era through geoethics and semiotics, using as a "translator mechanism" one of the key notions of Peirce semiotics: the semiotic triangle (De Pascale & Dattilo, 2015, 2016). On the one hand, we employ the geoethical paradigm as a possible interpretative framework for such processes (in other words, we identify in the geoethical paradigm a significant exemplification of hippocratic type, according to some scientists) (Matteucci et al., 2012).

The 'Hippocratic Oath', through which young physicians still today express their ethical responsibilities, represents the first written manifestation of the value inherent in the moral obligations that arise from the possession of specific knowledge that has practical consequences (Matteucci et al., 2012). Matteucci and others scholars (2012) identified an analogy between a geoscientist's intervention locally and around the globe and the role of a physician regarding his/her patients and, more generally, the health of the population.

On the other hand, we use the triangle "geology/geography – planet illness – society", as a metaphor of the principles and the processes inherent Anthropocene era, able to return them through the semiotic triangulation of Peirce (De Pascale & Dattilo, 2015, 2016).

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Teaching resilience and educating to seismic risk reduction at school: a geoethical path in Aiello Calabro, southern Italy

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Keywords: Calabria, geoethics, resilience, school, seismic risk management.

In collaboration with the geography of risk, geoethics forms an important component to inform the population and to further develop integrated risk management approaches that can enhance the resilience of communities (De Pascale et al., 2014). The resilience of a society to a hazard depends on the pre-disaster infrastructure and on adaptive capacity (Pelling & High, 2005; Gaillard, 2007), and on the nature of the hazard and its impacts (Donovan & Oppenheimer, 2015), but also improving communications, awareness of risk complexity and levels of preparation would increase a community's resilience and allow for more effective planning (De Pascale et al., 2015). The resilience has become a key concept even within geoethics, which has many common interest points with the human geography. Geoethics promotes geoeducation, aiming at organizing effective teaching tools (Bezzi, 1999; Peppoloni & Di Capua, 2015), at developing awareness, values, and responsibility, especially amongst young people (Peppoloni & Di Capua, 2015).

This work wants to verify the existence of any link between a good/appropriate resilience and a good/appropriate risk management (iapgeoethics.blogspot.it). Therefore, a survey was conducted at the primary and secondary school of Aiello Calabro (Calabria, Southern Italy), as part of the PON projects (National Operational Programmes) with the following objectives: to bring out the knowledge actually possessed by the children on practical and theoretical aspects of geoethics as illustrated during the classroom lessons and their perceptions related to earthquakes; to compare the knowledge and opinions of children on seismic phenomena in order to eventually highlight differences or similarities that may occur between the primary and secondary schools' children; to use the data collected as information to design and implement new activities and new information tools aiming at improving the activities of seismic prevention (www.iapgeoethics.blogspot.it).

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Blog dell'International Association for Promoting Geoethics (IAPG): iapgeoethics.blogspot.it

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Macroseismic intensity evaluation for the seismic hazard assessment in the third millennium

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Keywords: Macroseismic Intensity, Esi scale 2007, seismic hazard.

The aim of this paper is to highlight the importance of the proper assessment of macroseismic intensity evaluation of earthquakes, that can be considered "ethical" for defining the seismic hazard of a region. The macroseismic intensity represents the classification of the earthquake effects on people, buildings, and also on the natural environment.

The intensity evaluation of an earthquake is, even today, essential for two reasons: the first one is related to the time window, since the intensity values include a period of time of thousands years (from the paleoseismological and historical earthquakes, to the recent ones) while the magnitude estimates are available only since the middle XX century; the second reason is that the intensity allows us to assess the macroseismic effects also where buildings are absent (for example in desert areas) considering only the environmental effects.

Currently, nearly a hundred of macroseismic scales are available and used worldwide (Gaudiosi et al., 2014).

Italy, characterized by high seismicity level, shows old traditions in the classification of effects induced by the seismic events. Actually, some of the oldest cartographic representations, such as a map of the 1564 earthquake in the Nizza area (France), and the maps of the great Apulian 1627 earthquake (De Poardi, 1627; Greuter 1627) could be considered as authentic forerunners of the modern macroseismic scales. The first intensity scales accepted across the world were the de Rossi-Forel (1883) and the Mercalli scales (1902). The common macroseismic scales such as the de Rossi-Forel, the Mercalli, the MCS, the Modified Mercalli and the MSK scales estimate the effects on the environment as diagnostic elements relevant for evaluating the intensity degree of the earthquakes. These scales are nowadays supported by the new Scale ESI 2007 (Michetti et al., 2007) that assign the intensity only on the basis of the effects triggered by earthquakes on the natural environment. Actually, recent studies have provided clear evidence that geological and environmental effects, which have been currently collected in up-to-date database, provide essential information for intensity assessment and therefore they represent a valuable contribution to the seismic hazard definition.

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A new paper on Geoethics: THE "Laudato Sii" ENCYCLICAL LETTER by Pope Francis ON THE CARE OF our COMMON HOME, Planet Earth

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Keywords: Geohethics, Georesources, Planet Earth, Pope Francis.

Recently, on May 24, 2015, Pope Francis published its "Laudato Sii" encyclical letter on the care of our common home, planet Earth.

The topicality of the theme, along with simple content, yet its highly accurate time from a scientific point of view, have meant that the document was received with great interest, not only by the Catholic world, but also by scholars, scientists, and citizens who are concerned about health of our planet and the living beings that inhabit it.

Numerous reminders on the aspects and principles of Geoethics can be highlighted by a careful reading of the document, so much so that Pope Francis, in an article on the IAPG site, has been called "the most popular representative of geoethics in the world" (Gabor Paal, 2015: http://iapgeoethics.blogspot.it/2015/07/geoethics-anthropocene-and-pope-by.html)

Among the themes discussed we can identify some of the fundamental principles underlying the study, protection, management and use of geo-resources according to a geoethic approach:

- The relationship between the fragility of the planet and human fragililty: climate change, the lack of basic resources such as water and biodiversity loss threaten the quality of human life and human dignity becoming because of discrimination and conflict among peoples;
- The reciprocal relationships between human beings and environment: in consequence of interconnections between the various components of the planet (earth resources and living beings) is crucial the role of each geoscientist and of every citizen to work for the good of society in order to ensure the responsible use of georesources and their universal destination;
- The need for new paradigms ,no longer based on the technological manipulation, the technocracy and political and economic power derived from them; products of science and technology should be aimed at a "new narrative" of the world and based on a geoethic horizon, the service of a more social, full and integral progress, also including diversity;
- The integral ecology: the protection and care of the Earth-system are realized through a careful and responsible management of earth resources, a cure of the public spaces and the landscape, the creation of transparent relationships between scientists, decision-makers and citizens in the context of decision-making;
- The principle of intergenerational justice, under which it is the responsibility of all to deliver a habitable Earth to future generations.

Such attitudes are the main guidelines to be translated into action, good practices and new lifestyles aimed at redefining the concept of progress through a concrete commitment to the education of citizens, in order to establish and grow in a respectful and fruitful alliance between humanity and Planet Earth.

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Ethics of Geodiversity, geoEthics for Diversity: added values for Unesco Geoparks

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Keywords: Geoethics, Geodiversity, Geoheritage, Geoparks.

The difficulties to be overcome for the international recognition of a UNESCO Geopark are not limited at finding well representative geosites of the local geoheritage. Even the best strategy for sustainable geotourism could be inadequate to ensure its success of a proposal, if it is not permeated with ethical values, in the sense of the term introduced by Aristotle to indicate analyses and reflections on human operating behaviour. An ethical approach is therefore related to the modes of both acquisition of knowledge on geodiversity, and to its disclosure, essential to achieve truly collaborative management of local geoheritage.

For successful Geoparks we are therefore proposing to develop an Ethic of *Geodiversity*, which allows to:

• *acknowledge* and improve the awareness geodiversity from the experience of everyday life: becoming aware of the responsibility of man in the earth resources management, recognizing the need to reconcile the geosciences with the human sciences, in particular ethics;

• *locate* Geodiversity and geoheritage sites. To achieve this goal we need to develop a scientific method that analyzes geoheritage components in space and time;

• *define* Geodiversity according to scientific literature and established methodologies, and:

• *use* appropriate images, maps, documents, models for representing it;

• *evaluate* geoheritage from a scientific point of view;

• *conduct* scientific activities with the recognition of certain ethical rules.

Similarly it is proposed to apply the concept of *Geoethics* (http://www.iapg.geoethics.org) to facilitate the balanced management of the (cultural, political, social) diversity of a Geopark. But to talk about *Geohethics* we must to:

• *know and recognize it*: to become aware of the responsibility of man in the management of Earth resources, recognizing the need to reconcile the geosciences with the human sciences, in particular ethics;

• *locate it*: to find a proper geoethical approach to goals, methods and results of Science;

• *define it*: according to scientific and epistemological foundations (bibliographical references, methodological approaches and experience of authors of the past);

• *codify it*: uniquely define a code of ethics for being explicated;

• *fully apply geoethics*: identifying methodologies relating to scientific research, land management, teaching and dissemination;

• *make it easier* through a simple language and a shared knowledge to the greatest number of people (use of social media, involvement of public institutions);

• make it accessible, for example through the provision of geoheritage for the disabled.

In conclusion: an ethical path for building Geoparks can spread geodiversity awareness through different cultures. More: a geoethic approach to geodiversity can reconcile the diversities (cultural, political, social) of a territory, also contributing to promotion of solidarity and peaceful coexistence, and to increase the quality of life of local populations.

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The natural capital challenges in the Democratic Republic of Congo: a geoethical emergency

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Keywords: biodiversity, Democratic Republic of Congo, geoethics, natural resources, Rwanda.

The paper will cover aspects of emergencies linked to a Sustainable and Responsible Development in the Democratic Republic of Congo. In fact, Congo is one of the richest countries in the world in terms of gold and diamond mines, important minerals in the electronics industry such as Coltan, and in terms of biodiversity — flora and fauna. But Congo is also one of the world's most troubled and poorest countries. The major part of the rebels' activities consists of abuses against civilians and illegal exploitation of natural resources, be they metals, ivory or wood.

During the civil war in Rwanda, in the early nineties, over half a million of Rwandan refugees were forced by the violence of the fighting to take refuge in the Virunga National Park in the Democratic Republic of Congo: the forests were plundered of their timber and wildlife; even the mountain gorillas, endangered species, were killed and used as food.

It should be noted that in the north of the Democratic Republic of Congo there is one of the world's largest areas of the equatorial forest, hence, very important in the fight against climate change. One aspect that is often not fully taken into account in the study and analysis of conflicts is the fact that in addition to being a human and economic catastrophe, conflicts represent an ecological disaster.

Congo needs a geoethical model to reach an unity and a permanent equilibrium, which would guide the Democratic Republic of Congo to an unified management of the natural resources of the territory.

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The importance of environmental education in Niccolò Machiavelli's thought in the context of the Italian Renaissance: a geoethical model

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Keywords: environmental education, geoethics, Machiavelli, Renaissance, Rome.

The importance of the environmental and geoethical education is also present in the thought of one of the greatest intellectuals of the Italian Renaissance: the philosopher Niccolò Machiavelli (1469-1527) (Liserre & De Pascale, 2016).

In the "Discorsi" of Machiavelli (1531), the natural character of the place where a city is built is a determining factor in the overall measure of the need on the character of the citizens; but the barren place, if can keep away the people from idleness, and thereby constitute an essential tool of virtuous civic life, prevents the development of the power which can be fostered only by the fertility of the site. It may give rise own laziness which hinders the development of virtue; and then, according to Machiavelli, laws must be to impose the need to produce good behavior through education. Already in the Renaissance, Machiavelli recognized the importance of establishing a harmonious relationship between man and environment and suggested that the institutions should give a virtuous model of environmental education (Ferroni, 2003; Liserre & De Pascale, 2016).

The physiognomy of the geographical and natural environment conditions in an essential way the exercise of civil life and the development of virtues. If the Rome's model imposes the primacy of fertile places, it happens, however, that, in his general conception of virtue and of historical dialectic, Machiavelli tended toward ultimately to increased functionality of the desolate places, which make difficult the life, and through the exercise of the need, make men more virtuous, keeping them away from the destructive threat of idleness. This aspect emerges from a different perspective, but convergent in "Asino" of Machiavelli (Liserre & De Pascale, 2016; Martelli, 1971).

Although the structure of a territory unequally, according to Machiavelli, can be changed by the foundation of new cities, an aspect to which the ancients placed special care, distributing and multiplying the population through the colonies, as highlighted in a passage of great historical and geographical interest in "Istorie Fiorentine" (Machiavelli, 1532, II, 1). In this passage, the relationship between city and territory, human building and natural habitat is configured as an action of civil institutions and the work of human groups on the rough and unhealthy hostility of the physical environment (Ferroni, 2003).

This passage is a topical question, considering the importance of human action which helps to change the places for their livelihood. Already in the Renaissance, Machiavelli identified the importance of a geoethical virtuous model for the citizens and the institutions (Liserre & De Pascale, 2016).

The political horizon of Machiavelli is determined absolutely by the preeminence of the city. Even today, the geoethical challenge of which Machiavelli is the precursor, concerns the sustainability of cities. It is a multifaceted challenge which involves the environment, the use of resources, the social and economic systems of the Anthropocene era.

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"Urban Fossils": a project enabling reflections concerning human impact on planet Earth

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Keywords: Paleontology, Trace fossils, Geoethics, Anthropocene.

As geologists, we think it is important to improve people understanding of the geosciences by stimulating their involvement in current research. This is an occasion for us to be in touch with society and therefore to reflect on the values upon which we base our research projects.

In this framework, we agree that nowadays a geoethical approach to the geosphere-society relationship is necessary also to improve public awareness of the interactions between human activities and the geosphere. Among other geosciences, paleontology is taught in schools and is often the subject of documentaries and newspaper articles, mainly dealing with exceptional findings or exotic localities, accessible only to professional paleontologists; in contrast, most students and adults have no opportunity to find real fossils in their daily lives, which is usually spent in urban environments.

"Urban Fossils" offers the opportunity of experiencing "fossil hunting" as an amusing search in urban environments by registering traces of "past actions" recorded in asphalt and concrete pavements and roads (bottle caps and bolts, but also traces of humans and other animals, load left by scaffoldings etc.); this in turn stimulate reflection on the processes enabling fossilization, nowadays and in the geological past, and on the amount of information that fossils provide us. Are "urban fossils" true fossils? Can we make a parallel with ichnofossils? If so, to which ethological category do they belong? Also, are we really sure that the rocks used in buildings and sidewalks do not hide true fossils?

"Urban Fossils" started as a photographic project by F. Cirilli, and developed into a photo contest, a travelling exhibition, and a book.

The exhibition is composed of selected pictures, including ten urban fossils from the contest and the photographic series "Urban Fossils" by F. Cirilli; it has been organized in collaboration with the PROGEO-Piemonte project, Muse-Museo delle Scienze di Trento, and the Regional Museum of Natural History of Torino; starting from autumn 2015, it was and will be hosted by several national and international museums of Natural History (Trieste, Bergamo, Genova, Perugia, among others).

The book contains the pictures on display and chapters dealing with aspects of paleontology using plain language (Fossili Urbani from the beginning ; personal reflections of a photographer; Fossils from the anthropocene; Traces and footprints; Ichnofossils in town; Urban stratigraphy; Fossils and architecture; Educational proposals to free the imagination).

"Urban Fossils" is therefore an ongoing project, with a great interdisciplinary value, that represents an opportunity for both geoscientists and society to become more conscious of their role and responsibility in everyday life activities, ultimately improving the awareness that mankind is an active "geological" agent impacting on our planet Earth.

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Will a geologist choose the environmental ethics or the economy?

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Keywords: environmentalism, mining ethics, economy.

Since the very first appearance of human being, the mother planet earth has always kindly hosted us and generously supplied our basic needs to live. Through its dynamic billions years-old life, it has always reached in balance with its all natural events until the time that growth of the population, overconsuming and wastefully using the natural resources, and leaving the unnatural and unreturnable materials in the nature began to imbalance and devastate it. On the other hand, the aforementioned factors and their subsequent effects are inalienable parts of today's life. To maintain and surpass the current civilization standards, a strong economy is demanded and the strong economy inquires the resources and the technology that so far has mainly played a role against the environment. Yet, even having a strong economy, but without an environment to meet the primary needs, human can't live. As a tangible example of this, a simple mining activity can be mentioned. Extraction of a natural resource, let's take the fossil fuel, via direct or indirect ways, supplies energy, serves for technology, and maybe more importantly, feeds people through providing many jobs (economy increment). This is while from the other standpoint, the same activity imposes the loads on the environment which in return, will need technology and consume energy and budget to recompense the damages (economy decrement). Thus, the contradiction of choosing the more important hand, or equilibrating the human's greed and the necessity of following the ethical rules comes out. Bringing forth the questions about ethics is easy, but the real art would be finding a rational response to satisfy both hands. The crucial task of determining a balance level between our responsibility of fairly keeping the ecosystem and at the same time, responding the needs of a today's technology and economy is very complicated and strongly depends on how much we are able to analyze the both sides of the equation, so that we can assign the proper weight and priority to each pan which indeed are complementary to each other. Here is the point that science, and geology in particular, comes to help us. The more we know about Earth sciences, the clearer view we will have of its essence and consequently will be capable of resolving their affiliated problems. Therefore, deeper investigating the geo, passing the outcomes of our studies and experiences to the hand of next generations, taking the responsibility of our decisions which substantially affect the nature, and commitment to a sustainable development not only are the ethical rules to be followed, but also will conduct us to diagnose our environmental issues more clearly and comprehensively that reciprocally can be serve to set up stronger pillars of the economy. The environment is in the service of human, and human is good to guide his science on the perfection of environment.

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Review of the performance of the crisis management centers in Iran and analysis of these institutions in Bam earthquake

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Keywords: Bam earthquake, vulnerability, responsible, crisis management.

Iran in the terms of topography, geological and anthropogenic component is among the world's 100 most disaster-prone countries. Each year, disasters such as floods, earthquakes, drought and imposes losses of life and huge economic losses in the country. Earthquake is one of the most devastating natural disasters that threatens most towns and villages in Iran. In Bam earthquake (26 June 2003) with 9 Mercalli Intensity destroyed 70-80 percent the city of Bam; More than 40,000 people were killed and 25,000 were wounded, the high number of casualties of the earthquake compared to the same accident is indicative of a very high vulnerability. But the earthquake alone was not responsible for the high number of human and financial losses and other major factors including wrong determination of the location of earthquake played a role in this regard. Now 13 years have passed since the sad event yet the no organizations or authority in this area was not regarded guilty and is still crisis management centers in the provinces of Iran act poorly. In this paper, after reviewing the Bam earthquake and the factors influencing the severity of the incident, solutions are provided for improving crisis management centers in the Iranian cities.

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Forensic soil analyses in a simulated murder case

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Keywords: Geoforensics, Forensic Geology, Particle Size Analysis, Laser Diffraction.

The better practice for the evidence collection is to examine firstly, colour and particle size of questioned samples, and secondly to search for unknown samples with analogous sedimentological and mineralogical features to questioned samples (Murray, 2004; Ruffell and McKinley, 2008).

In the present research, based on a simulated murder case, the colour and Particle Size Analysis (PSA) were firstly determined on N. 6 questioned samples from Victim's dresses and boots. The evidence collector, taking in mind those characteristics, sampled N. 21 soil evidence on the Crime Scene and on items or localities related to three Suspects (S1, S2, S3).

Colour was determined by using the Munsell color chart and spectroscopic analyses. Comparison of soil colour from Victim' questioned samples and Suspects' unknown samples showed the following results: Munsell colour of Victim samples resulted to be the same of Suspect S1 and Suspect S2, whereas colour of Suspect S3 and of crime scene did not compare. Spectroscopic analyses of the colour allowed to further compare Victim and Suspect S1 samples, being a negligible difference between the soils, and to better individuate discrepancies among the Victim and Suspect S2 samples, notwithstanding the Munsell colour is the same.

As concerns PSA, this technique was easily applied in the present case as the quantity of the samples was high (being the murder occurred during a rainy day). The studied forensic soil gravel and sand fractions were analysed by mechanical sieving using sieves with 5cm diameters. The cumulative curves related to victim soils resulted to be characterized by the same trends of the Suspect S1 soils and overlapped those curves. Differently, the cumulative curves of the victim soils showed different trends with respects to those of Suspect S2 and S3 and did not overlap.

Such results are confirmed by PSA realized by laser diffraction, being frequency curves, related both to victim and Suspect 1, unimodal and overlapping. Differently the unimodal distributions of the victim soils strongly differed from Suspect 2 and Suspect 3 samples, being these latter characterized by bimodal curves.

In conclusion, the Murray' principles for the better practice, if carefully followed by specialized evidence collectors and if the samples are conspicuous in quantity, can allow to better administrate both economical and time resources during investigation of serious crime cases, before to carry out more specific and expensive analyses of physical evidence on any collected sample.

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The use of digital surface, terrain models and geophysics to define search priorities for clandestine burials in a GIS-based Red-Amber-Green (RAG) system

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Keywords: Forensic Geology, GIS, criminalistic, RAG map, clandestine burials, search teams, GPR, tomography.

Forensic geology involves the application of geoscience to help with the investigation and resolution of criminal cases (against people, environment, and heritage). In many of such criminal cases, the offender conceals objects such as special waste tanks, weapons, explosives, or cadavers, digging the object in and burying them in the ground.

This research focuses on the development and creation of a RAG (Red-Amber-Green) map, i.e. a thematic map indicating the high (red), intermediate (yellow) and low (green) priority search areas of clandestine burials in the ground. The RAG method provides thematic maps to assist with the deployment of appropriate search assets to ground searches for the potential location of buried objects/bodies. Consequently, RAG maps are helpful to assist in the strategic management and deployment of search teams and search dogs.

The RAG system is generally designed with reference to specific mapped features, such as soil diggability, slope acclivity, vegetation type, anthropogenic structures, visibility by eyewitnesses, etc. In this paper the RAG system is implemented along with a Geographical Information System (GIS) and geophysical survey, as applied to a search for a simulated homicide grave in a test site located in Italy. The GIS-based map uses a digital elevation model including both a digital surface model (very useful as the site was afforested) and a digital terrain model. Once the high priority areas (red) are defined, strongly reducing the original extent of the area under investigation, a geophysical survey was realized in the high priority zones; a 3D tomographic survey defined the diggable soil thickness, where subsequently GPR was used to define the localized and identify the area of the homicide grave.

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Are there geoethical aspects involved in geohazard assessment? The case of tsunami hazard quantification and mapping

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Keywords: Geohazard assessment, tsunami, hazard mapping, geoethics.

Geohazard assessment is more and more required by communities and societies for guided and knowledge-based planning. For example, seismic and, more recently, tsunami hazard assessments have been undertaken in several countries of the world and globally for the whole Earth planet with the aim of providing a scientifically sound basis to the engineers, technicians, urban and industrial planners, politicians, civil protection operators and in general to the authorities for devising rational risk mitigation strategies and corresponding adequate policies.

This presentation is focused on tsunami hazard evaluation taken as an exemplary case, though concepts and conclusions can be applied to most geohazards involving rare and high-impact processes. The main point is that the real value of all tsunami hazard studies (including theory, concept, quantification and mapping) resides in the social and political values of the provided products, which is a standpoint entailing a number of relevant geoethical implications.

The most relevant implication regards geoscientists who are the subjects mainly involved in carrying out hazard evaluations. Viewed from the classical perspective, the main ethical obligations of geoscientists are restricted to performing hazard estimations in the best possible way from a scientific point of view, which means selecting the "best" available data, adopting sound theoretical models, making use of rigorous methods…

What is outlined here, is that this is an insufficient minimalistic position, since it overlooks the basic socio-political and therefore practical value of the hazard-analysis final products. Tsunami hazard reports and maps are products that should be usable, which means that they should meet user needs and requirements, and therefore they should be evaluated according to how much they are clearly understandable to, and appropriate for making-decision users. This open the path to a new geoethical perspective where geoscientists and users interact cyclically. Theory and methods themselves are not determined a-priori, but they result also in response of geoscientists-users interactions. Further, user needs can be modified ex-post in response to geoscientists elaborations. These two-way feedback actions are the main challenge for the present generation of geoscientists, but unfortunately they are not adequately reflected in the today university educational systems.

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Geoethics: is it a new science or a new focus in geosciences?

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Keywords: Geoethics, Geosciences, responsibility.

Geoethics is a relatively new entry in the panorama of geoscientific culture and has found space and resonance in scientific congresses and publications. There is an increasing recognition that it raises important and crucial issues. In spite of this, or possibly as a consequence of this rapid growth, there is a lack of foundational concepts defining its role and scope. Has it to be viewed as an independent science, at the border between geosciences and ethics? Is it a discipline classifiable as one of the many branches of geosciences, or rather as a branch of ethics? Is it rather a social science? What are its main themes? There is a need for a systematization of the topic, and today many who treat of geoethics, do indeed speak different languages and use the same words with different meanings, as it happened very often in the mankind history when new ideas come out on stage. While waiting for a definition of its status, here it is stressed, that geoethics has to mark a cultural progress in the way geoscientists see their role and their responsibilities, at a scale from local to global, to ensure that today's and future societies are built and grow with the knowledge and awareness of opportunities and constraints provided by the basic processes of Nature.

SESSION S37

Geosciences at school: state of art and perspectives – Le geoscienze a scuola 2016

CONVENERS AND CHAIRPERSONS

Eleonora Paris (Università di Camerino)
Manuela Pelfini (Università di Milano)
Rosa Di Maio (Università di Napoli Federico II)
Paola Petrosino (Università di Napoli Federico II)
Sofia Sica (Associazione Nazionale Insegnanti di Scienze Naturali)

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Esperienza didattica di coltivazione di Idrocarburi per studenti dell'Istituto Agrario

Altieri C.

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Keywords: Didattica, Geoscienze, giacimenti petroliferi, Istituto Tecnico Agrario.

L'esperienza didattica ha riguardato una classe terza dell'Istituto Tecnico Agrario Statale di Piedimonte Matese (CE) con indirizzo Ambiente e Territorio. L'argomento proposto è stato il cracking del petrolio. In una prima fase i discenti coinvolti hanno eseguito una prima ricerca sui giacimenti petroliferi (come vengono individuati), su come viene eseguita la perforazione dei pozzi a terra ed in mare, in cosa consistono le piattaforme petrolifere, al trattamento, allo stoccaggio del petrolio. In una seconda fase altri discenti del gruppo classe hanno eseguito una seconda ricerca sulla raffinazione del petrolio su come viene avviato alla distillazione frazionata e su come vengono ricavati i vari tipi di idrocarburi. La metodologia didattica applicata all'esperienza è stata l'apprendimento per scoperta e quello del problem solving. Al termine i discenti dei due gruppi hanno prodotto un power point unitario dove hanno focalizzato i punti salienti. In conclusione possiamo dire che i discenti si sono molto divertiti perché hanno appreso contenuti che al di fuori del contesto socio culturale in cui vivono; infatti molti di loro abitano in frazioni ed hanno aziende zootecniche a conduzione familiare. La media dei voti è stata molto alta, dimostrando una apertura in questo campo scientifico di non stretta pertinenza e indubbiamente specifico. Ciò lascia ben sperare per una eventuale prosecuzione del loro futuro corso di studio nell'ambito delle Geoscienze.

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Teaching of geosciences in schools: the road is "touch"

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Keywords: geosciences, school, learning experience.

The perception of the physical and geographical space, in which we were born and we move, is a feature that we have from early childhood but in the period between seven and ten years of age that we begin to interpret the places, shapes, objects and to represent them properly. The development of consciousness, of awareness and attention to our environment, necessarily passes through a specific training in the field of geoscience and it is the duty of teachers, researchers and professionals to integrate the educational paths of primary and secondary school through events and educational events dedicated. Knowing identify and recognize the actual connection between the mental representation and the reality of the facts and underlying mechanisms, may be the key to a concrete dissemination of geoscientific culture.

Some recent and interesting learning experiences to which was attended by many students and the positive feedback from the Departments of Educational Institutions involved authorize to continue on the path of direct cooperation between the school and the academy.

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Earth Science Education in Brazilian schools: current situation and perspective

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Keywords: earth science education, brazilian schools system, curricula.

Brazil is a federation of 27 states and has a population of 202.033.670 millions of people. In 2013 more than 37 million of child and teenagers were enrolled in school system. The school in Brazil is compulsory till 17 years old. The majority of students population attend public school, 15% are in private school. Brazilian school system includes primary school, that is divided in two sublevel called primary school early years (age 6 years till 10 years old) and primary school finals years (age 11 years till 14 years old), and secondary school is (age 15 - 17 years old. Primary and secondary school are standard without options or specialization. There is technical school that the students could make separately or at the same time of regular schools. The percentage of students that attend technical schools was approximately 4%. Among this technical schools there are some of them that have a high content of Earth science but only few students are enrolled in this kind of school. In Brazilian schools doesn't exist a discipline like Earth Science or geology devoted to teaching Earth Science. By the way, there are some contents of Earth science content in the primary school in the natural sciences and geography subjects. In secondary school as well there are some content of Earth Science taught in biology, chemistry and especially in geography. This division is according to the national curriculum guidelines. That means that we have a compartmentalization of the subjects and rarely there is a conversation between the teachers of different subjects, the knowledge became fragmented and insufficient to promote the comprehension of Earth as a dynamic and complex system (Toledo, 2004), despite of the national curriculum guidelines consider geosciences an important topic to being teaching. With a so huge territory and great reserve of minerals, oil and water, unique ecosystem as Amazonia, Cerrado and Mata Atlantica and a territory affected by flood and drought it's really important for Brazil citizen to have a basic understand of the Earth system science in order to respond to several Geoethic issue that the country are facing. With the new national common based curricula under discussion we are proposing a new Earth Science Curricula based in International Geoscience Education Organization International Geoscience Syllabus.

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Learning paleontology on the field: the Cà del Frate fossil locality (Middle Triassic, Monte San Giorgio, UNESCO WHL, Italy)

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Keywords: Triassic, Monte San Giorgio, Kalkschieferzone, Paleontology, fossil locality.

Monte San Giorgio (Lombardia-Canton Ticino) is one of the world's most important fossil deposits of the Middle Triassic period, between 247 and 237 million years ago. The exceptionally well-preserved fossils of this mountain have been extracted and studied by Italian and Swiss palaeontologists since 1850. Thousands of fossil specimens of reptiles, fishes, invertebrates, insects and plants, many belonging to rare or even unique species, have been discovered up to now. This paleontological area gained international recognition when its inscription to the UNESCO World Heritage List was formalized in 2003 for the Swiss side, and in 2010 for the Italian side. The inscription was motivated specifically for the extraordinary richness of the Triassic marine fossil record.

Since 2010, a series of actions have been taken to enhance the visibility and the accessibility of Monte San Giorgio. Among these, the project for increase the accessibility to school groups, included people with disabilities, of the Ca 'del Frate (Viggiù– Varese) fossil site, one of the most interesting of the area.

Fossil collection in this locality has been random until the beginning of the 80's when systematic field works on the "Kalkschieferzone" were started in a framework of a joint project of the Dipartimento di Scienze della Terra"A. Desio" of Milano University and the Civico Museo Insubrico di Storia Naturale di Induno Olona. Field works led in the fall 1996/spring 1997 on a surface of about 12 square meters, allowed to collect thousands of specimens, both vertebrates and invertebrates, and systematic and paleoenvironmental studies have been extensively led.

The privileged position of the outcrop, easily approachable also by cars, made the site as ideal to plan, after appropriate technical actions, educational activities on field. The project, with financial support by the Ministero per i Beni Culturali, was realized in 2014-2016. After having secured and cleaned up the outcrop, the access to the site and the area itself have been paved and explanatory panels, showing the characteristics of the locality and the information regarding research, have been placed. A totem-like structure was built to hold samples with the main lithologies visible on the outcrop and the relative explanatory labels. The area around the fossiliferous levels has been expanded and equipped with stone seats and table to accommodate school groups and their guides.

In order to allow people with mobility impairments or with visual disabilities taking advantage of the uniqueness and the great scientific value of the site, some devices have been realized, such as the regular flooring and the continuous handrail following the path. The explanatory labels and some drawings of the most representative fossils are coupled with a Braille version.

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The Natural Integral Reserve "Cave of S. Ninfa" (Trapani, Western Sicily) – An educational – didactic path in the environmental respect's field

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Keywords: didactics, laboratorial activities, field activties.

In this notice is illustrated the experience of a didactic unit relating to the guided visit at the Natural Integral Reserve "Cave of S. Ninfa" (Trapani, Western Sicily), planned for Artistic high school in Trapani, in the field of an educational – didactic path of ecologic – environmental type. The main purposes of this activity were: to make understand the relevance of institution of protected areas for the biodiversity's safety; to develop the growth of a green awareness, necessary to change the behaviour and the lifestyle, through aware choices oriented towards a sustainable development; to start a dialog between school and territory for the fruition of experiences and educational contents, so that it'd become an active part in the processes for the construction of the knowledge, according to what is suggested by Italian Ministerial guidelines relative to *"Environmental education for the sustainable development"*.

The didactic unit was organized in a first theoretical part, where the next topics were debated:

introductory knowledge activity about the site of the guided visit: informations about the geologic, geomorfologic and ecological characteristics of the protected area and the fundamental faunistic and floristic features have been provided to the students;

and in a second practice part, that concerned:

activity in the field relating to the guided visit at the R.N.I. "Cave of S. Ninfa": it was used the research in the natural environment by perceptive and exploratory moments and the collection of informations. Therefore, it was utilized a training model, where the activity of field was conducted to implement and verify the acquired skills and to supplay further theoretical research (educational and informative model, that leads a promotion of the scientific logic);

laboratorial activities: the students had made graphic works about three specific topics, to which was followed a thought phase, through series of questions expressly formulated and inserted in a form, in order to accustom the students at the autoexamination's ability about the conducted work. This activity had been advantageous to introduce the communion moment of the experiences lived which had caused the creation of a rules list to have in a protected natural environment. This strategy allowed to strengthen some of the predetermined purposes, like: the sense of awareness and responsibility of the students towards the nature; the ability to control the own behaviour in respect of the others and the environment; to stimulate the students to start, in the daily life, responsible and motived lifestyles aimed at the environment's safety.

The activity conducted in the field and the following laboratories had revealed themselves, for the realization of the objectives and the predetermined purposes, a more incisive instrument than the normal didactic procedure, increasing the abilities and the potentialities of all the students.

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Kids geosciences labs: the experience of "Sabato al Museo" 2016

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Keywords: Geosciences, European Night at the Museums, Kids laboratories, geological knowledge.

During the events "Sabato al Museo" (7th and 21th May 2016) and the European Night at the Museums (21th May 2016), organized by the Polo museale Sapienza (https://web.uniroma1.it/polomuseale/), the Italian Geological Society (SGI - http://www.socgeol.it/) designed and realized six laboratories for children. These were carried out at "Sapienza University of Rome" inside the MUST (University Museum of Earth Science) and the Museum of Anthropology.

The main goal of these labs was to mediate the research activities performed by the Sapienza University in different fields of geosciences to an audience of children (from six to twelve years old).

The laboratories were holded by selected experts in teaching and disseminating for children. The activities were organized in two phases. In the first phase (about 15 minutes), the operators introduced the audience in the topic of the laboratory by means of multimedia material, involving children with questions and discussions. In the second phase (about thirty minutes), the children carried out experimental activities using the proper scientific methodology.

The SGI organized and realized the following laboratories: "Dinosaurs… even in Italy!" (in collaboration with MUSE – Science Museum of Trento); "Footprints"; "Microworlds" (a micropalentological laboratory); "Prey and predators" (in collaboration with PaleoFactory Lab – Sapienza University of Rome); "Discovering our history: apes, fossils and man" and "Ancient weapons".

About 800 children attended these laboratories. The feedback of the audience proved to be very positive, as testified by ex post questionnaires; they had indeed the opportunity to explore topics that commonly capture their imagination. We are deeply convinced that these activities can greatly contribute to expanding the cultural background of the younger generations, in particular the geosciences that unfortunately are still too neglected.

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3D geological modelling and education: teaching geological cross sections with a 3D modelling software to improve spatial thinking skills in geoscience students

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Keywords: 3D modeling, geological cross sections, spatial thinking skills, teaching geosciences.

The skill in "reading" two-dimension representations (typically geological maps) as symbolic images of the real world is critical for a geologist. Teachers have thus to face the difficulties that several students have when reading geological maps. Furthermore, when students fail, the consequence is often a frustration with the successive reject of the subject. The skill to understand 3D objects can be typically evaluated with the analyses of the geological cross sections produced by geology students.

Spatial thinking skills are related to two main facts: 1) a natural predisposition in the visualization of complex objects and 2) a good training to develop 3D visualization skills. Whereas in the first case the role of the teacher is often ancillary, in the second case, teachers need to find a way to improve 3D visualization skills with specific tools and specific exercises.

In the past, the supports for this educational training was provided by physical models or by perspective images. The development of 3D geological software packages recently provided tools for geological modeling that found applications in different fields of geology. In the academic formation, nevertheless, students learn the basic of 3D geological reconstruction with classical tools, whereas the use of 3D software packages is limited during their education and they mostly meet these tools for professional applications after their degree.

At the Earth Department of the Università degli Studi di Milano we introduced the educational use of a 3D modelling software (Move ™, produced by Midland Valley Exploration LTD and provided to our department in the frame of the Field Mapping Initiative) since the Bachelor courses (on voluntary basis), in order to stimulate the 3D visualization skills of the students. Move™ has been used on simple geological situations selected from a number of educational books: students were guided in the production of 3D geological models from digital raster images of simple geological maps, following all the process of data input and elaboration (including DTM production). 3D visualization at different step of the model development strongly improved the skill of the students in the visualization of geological volumes, speeding up the process of learning.

The feedback of this procedure has been strongly positive, with students that, after learning the basic use of this 3D modelling software, asked for the application of the method to real and more complex geological cases.

The use of 3D software packages for the modelling of geological bodies during the educational program potentially increased the precision in the geological mapping process, as the students were able to verify that also minor inaccuracies in data representation are strongly highlighted when geological data are handled in 3D models.

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Epistemological aspects of Earth Sciences

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Keywords: Didactics, Key concepts, Epistemology, Earth Science.

The knowledge of some specific key points of the Earth Sciences allows to better explain this discipline to the students. In fact, among the natural and experimental sciences, the Earth science can be considered a discipline "sui generis": in this, a direct investigation is often not possible so, there is a very strong need to use simplified models that represent the only feasible way to obtain a “plausible idea" of something which cannot be known through direct experimentation. Unlike other experimental sciences, such as physics, chemistry and biology, who developed over the eighteenth and nineteenth centuries, the global model of Earth Sciences, the plate tectonics, developed only on the late sixties of the last century, often causing in this subject that opposing views can coexist stably at the same time. This aspect of indeterminacy, if properly highlighted, however, constitute a special reason in order to qualify the geology, which, compared to other disciplines, is closer to the positions of the most recent epistemology. The new epistemology, in fact, strongly rejects the assumption of a cumulative progress of science and underlines the positivity of the presence of several perspectives within a discipline. Finally, the Earth Sciences allow numerous connections with the theme of education for sustainable development (ESD). They allow focusing on several issues, such as the sustainable use of resources, the risk prevention, the urgent need for a comprehensive approach to environmental problems. So the students become aware of the responsibility of science not only to the environment and present societies, but also for the future of our planet.

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The learning objectives of geosciences at school

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Keywords: learning objectives, operational competences, transversal objectives, geological hazards, geoethics.

The learning objectives of geosciences at school can be divided into three basic categories, in line with EU directives on educational policy: cognitive objectives, operational competences, transversal objectives.

The cognitive objectives should be focused on the founding nuclei of the main disciplines which make up the earth sciences, recognizing the type and specialization of the individual disciplines, but at the same time understanding the complexity of geological phenomena and related general, fundamental and unifying principles, through the use of IBSE type methodologies (Inquiry Based Science Education).

Among the most significant operational competences to be acquired in the field of geosciences figure primarily the abilities to read, interpret, compare and digitally manipulate experimental data and their graphical representations in the form of tables, diagrams, thematic maps, satellite images, geological maps and related graphics (topographic bases and profiles, geological, stratigraphic and structural sections etc.). In all cases, the guiding principle of geoscience education is to be able not to mix scientific observations and related data of geosystems with interpretive explanations and models.

Transversal objectives for their educational value are particularly important for geosciences at school. A general goal is the capacity to frame the geological events in some founding principles of evolutionistic type, such as actualism, gradualism versus catastrophism, the principle of stratigraphic superposition, the isochrony of sedimentary bodies, the paleontological identity, the Walther's law of facies, the hierarchical cyclicity of geological phenomena. With appropriate examples illustrated by the teacher you learn to frame the natural events in the respective space-time scales, including the anthropic and historical ones, from the subatomic to the astronomical. The comparison between the different time scales lead to the concept of geologic deep time. Another relevant transversal objective is education-oriented knowledge and evaluation of the main geological hazards (seismic, volcanic, hydrogeological, from environmental contamination), which in turn is a fundamental building block for the development of a global geoethical awareness. The latter also develops through, among other things, knowledge and appreciation of the geological sites and culture of sustainable georesources. Educational strategies based on the development of geoethical awareness can produce in the medium term a substantial change in the mass behavior of citizens and an increase of the importance and the social role of geologists and other environmental engineers and scientist, also in orienting policy making.

Climbing walls in Earth Science education: an interdisciplinary approach for the secondary school (1st level)

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Keywords: Rocks, landforms, climbing walls, interdisciplinary approach.

Landscape and landforms are starting points for outdoor learning activities. These latter have been widely recognized as important tools in improving knowledge and comprehension of natural and human factors interacting on the Earth surface. Moreover, fieldwork favors the application of the interdisciplinary principles and links, allowing to reach the official specific goals indicated in the education programs, for different disciplines. In this framework, rock cliffs represent key sites for education in geo(morpho)logy as the wide outcrops show minerals, geologic structures and morphosculptures documenting the Earth history and the progressive landscape shaping by surface processes. Cliffs equipped for climbing represent open-air laboratories useful to get in touch with rocks features conditioning the progression on climbing routes. We present the results of an ongoing interdisciplinary educational project, (Gekologia) including mainly Earth sciences and physical education, addressed to students of a secondary school (1st level, 3rd year). The following specific ministerial goals were considered: i) the ability to classify the principal lithotypes (i.e., great families of rocks) according with their features and origin (Earth Science); ii) the competence to apply the acquired abilities in different environmental situations and to expect the result of a motor action (Physical education).

Previous researches allowed selecting climbing rock cliffs along the Ossola Valley (Western Italian Alps) in relation with their scientific and educational value (good exposition of rock features, easy accessibility, low grades for experts and beginners). During a first phase of the work, 4 classes were involved in a virtual path using home-made videos at 3 selected climbing sites and web based videos from sites all over the world to explore rocks from different morphogenetic contexts. During the “Gekologia Project” the same virtual strategies were proposed to 2 classes after a field climbing experience in Premia-Balmafredda (Ossola Valley). The field activities were preceded by lessons and laboratory experiences.

The climbing practice, organized by the school under the supervision and responsibility of alpine guides, focused on (i) the visualization of different minerals and geologic structures conditioning the climbing progression; (ii) the analysis of the motor action; (iii) the production of sketches of the climbing/geological environment. The modeling action of ancient glaciers and streams was observed during the fieldtrip in the “Glacial Garden of Uriezzo” (under the supervision of an official environmental excursionist guide), with the aim to identify the past and present geomorphic processes.

The first results confirm how an interdisciplinary educational approach including fieldwork and new technologies, favors the motivation of young students and represents a good strategy in learning.

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The use of virtual worlds in Geoscience teaching/learning

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Keywords: Virtual Worlds Geoscience education immersive environments.

Virtual Worlds represent an innovative strategy and an educational opportunity to learn in a socially-interactive learning community and in a immersive environment. However, in spite of the already recognized effectiveness of Virtual World as learning environments, still their application in science teaching-learning is very limited.

To experience this approach and evaluate its applications in Geoscience topics we used a MUVE (Multi User Virtual Environment) to address students of two age groups, 13-15 and 15-18 years old. A virtual island, the UNICAMearth island, was created in 3D using the software Open Sim and the Singularity viewer. Through an online access, the students experienced role-play activities built using the Inquiry Based Science Education (IBSE) approach with an adaptive path. Serious games were built to make the students pass ability steps, knowledge tests and solving problems. Following the path they carried out tasks and answered questions, planned to make them acquire specific knowledge as well as general scientific and transversal skills.

Since the use of simulations in virtual environments recreates contexts similar to reality, this characteristic can be effective to study an area and its transformations with time, with interesting possible applications in geoscience topics. In this work, several paths have been recreated in 3D environments, where the students, as avatars, learn with an immersive training: for example, a volcanic area to simulate eruptions, earthquakes, studying rocks and minerals as well as understand which events may occur in an area at risk of eruption. In each path, through IBSE questions, the students collect data and play the role of a geologist.

The paths have been tested in schools and they were found to be highly involving, increasing also social skills, cooperative working and connections with the teachers, even for the shiest children. The experimentation has shown that students learned in an engaging way, especially when the environment could be changed by the user. The effectiveness of learning and the interest in approaching these topics were especially high for those students usually lacking interest for science or missing attention and fitting in the traditional school teaching.

Being the first attempt to use the Virtual World in geoscience teaching, it is possible to conclude that their use can be very successful and it is possible to find interesting applications, both in school and in museum or in any educational environment where a recreation of reality is useful.

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Leghorn Quaternary Ecology: interactive variations on the theme. Project paths of alternative and transversal didactics

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Keywords: Museum, didactics, geodiversity, ICT.

Recently, MIUR and MiBACT have engaged in joint initiatives aimed to keep teachers up to date and to train students through a pedagogy of innovative and concrete assets.

The foundation is the knowledge of the culture places where students can exercise their rights of knowledge and maturation in contact with the cultural heritage, in a special educational space which is the museum.

In this context it is presented the project "Ecology of Leghorn Quaternary: interactive variations on the theme", winner of the national contest "Educational Projects in museums, archaeological sites, cultural and historical or cultural and scientific institutions" organized by the MIUR in 2015.

The project, presented by ISIS Niccolini Palli Livorno as leader of a network of schools of all levels, identified as "target structure" the Museum of Natural History of the Mediterranean (MusMed) with which has resulted co-design action.

The project focused on two main objectives: improve the knowledge, both teachers and students, of the material and intangible cultural heritage of the territory in a specific time span; engage students on the theme of conscious involvement of cultural heritage.

The students, led by the operators of Educational Services Department of MusMed, were involved in the exhibition design and setting up of a part of the archaeological finds discovered in the proto-historic necropolis of Parrana San Martino (Livorno), themselves recovered in the excavation campaigns of the last years, in the design and implementation of multimedia communication supports for foreigners and special needs public, digital applications, and a 3D diorama of the Vallin Lungo (San Vincenzo, Livorno) peculiar mine, contexted to the Etruscan period. Mines in this area have been dug along skarn mineralitation, including mixed sulfides, inner the carbonate host rock characterized by widespread karst phenomena (Cascone, 1993; Cascone & Casini, 1998): the analysis of this geologic variety, has allowed to introduce the geodiversity theme.

During the all experience students were asked to propose "their" point of view and their "narrative" mode of the new museum, becoming themselves the major players.

The project is ongoing and will involve both teachers and students even in the school year 2016-17.

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Cascone G. & Casini A. 1998. Pre-industrial Mining Tecniques in the Mountains of Campiglia M.ma (LI). In: S. Milken & M. Vidale, Papers from Third Annual Meeting Eur. Ass. of Archeologists, BAR International series 720, 4, 149-151.

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Climate change and glaciers. A didactic link between research and school

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Keywords: climate change, glaciers, geoscience education.

While researchers are aware of the relationship between climate and natural environment, the general public is not. The reason is that although this topic has comparatively high visibility, the people's lack of interest and basic scientific knowledge often distorts the way the problem is looked at. The natural setting for the communication of knowledge on the subject along with the promotion of a sustainable culture is school, with teachers playing a fundamental role. Unfortunately, ministerial guidelines and textbooks do not deal adequately with the subject especially considering the acceleration of environmental changes. This problem is at the base of the present study, as subject of a PhD project in Geoscience education at University of Camerino.

The first step of the project was to examine a number of school textbooks to evaluate what information on climate change is given and the educational methodology used. The results evidenced that the space dedicated to this topic is scarce and insufficient is also the information of the effects on glaciers. Then didactic activities were prepared to approach these topics, with a focus on the Alps, including: a) a package of 2 seminars in the classroom followed by a fieldtrip in areas of glaciological interest, b) a questionnaire to assess knowledge and competences acquired, as well as the environmental awareness; c) a general questionnaire used for the classes as control samples.

The experimentation is carried out in secondary (lower grade and upper grade) schools, with both Licei and technical schools, with collaboration of teachers and students from 3 schools in the area of Italian Alps and 1 in the French side with over 650 students and 28 classes. The location of the schools, all in the Alps, allow field trips to investigate the climatic changes of the past (morainic amphitheater of Ivrea, Piedmont) and the recent ones (Miage glacier, Aosta Valley).

The project, when concluded, will determine: a) the effect of the activities carried out in the different types of schools, allowing a comparison between Licei and technical schools, Italian and French schools; b) the level of awareness about the climate change, both in students participating the experimentation and those of the control classes; c) the effectiveness of the activities carried out and the suitability of the field trips.

Preliminary results show that: a) the students from both Licei and technical schools took advantage by the experimentation and the field trips allowed to attract their attention; b) the level of participation to the outdoor activities was intense for the lower secondary students, with interesting comparisons between French and Italian schools; c) the interest was so high that a Liceoclass carried out an experimentation in all the school using the "general" questionnaire, as a vehicle to raise the climate change awareness, creating a school project which could be extrapolated on a national scale.

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Laboratory activities for schools as integration to traditional teaching methodology

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Keywords: mineral and rock laboratory, practical activity, hands-on approach, teaching methodology, Geosciences.

Since some years the Earth Sciences Department of the University of Milan offers to high school students guided visits of its research and analytical laboratories. Such visits are aimed to show the most modern methodologies for the study of our planet and their applications in the study of solid materials and fluids also in non-geological fields. More recently, with the collaboration of the "Museo delle Collezioni mineralogiche petrografiche e giacimentologiche" of the Department (recognized as University Museum), laboratory activities on minerals and rocks have been proposed as a practical support to school teachers. The "fil rouge" of the activities is the link between theoretical concepts and the everyday experience. Following a "hands-on" approach, the students may directly observe and manipulate a large number of mineral and rock samples. Through continuous discussion inside the group and with some suggestions by the instructor, if necessary, they are leaded to establish criteria to form groups of objects, for example, separating minerals from rocks. Then they are invited to observe and describe the characters of the samples and to group them accordingly (for example, lustre, colour, crystal habit, hardness, cleavage for minerals; grain size, oriented structure, colour for rocks). The instructor continuously stimulates the discussion and helps to establish connections between the observed characters and the physical properties or processes causing them. Particular emphasis is given to minerals and rocks of common use in industry and applied technology as well as in the everyday life (salt, talc, feldspars for ceramics, ore minerals, gems, marbles and other stones used in architecture, etc.). The activities may be calibrated according to the level of knowledge of the class and the age of the students. The outcomes are mainly positive, since the practical activities represent a pleasant integration to the classical theoretical lessons and stimulate much interest in the study of minerals and rocks, often seen as boring arguments, as they are learned in a schematic and mnemonic way.

Although initially planned for high school students, similar laboratory activities have been successfully performed also with younger students, between 10 and 14 years of age.

Therefore, this kind of activities seems to give an effective contribution to the dissemination of geosciences among young generations and to an increased consciousness of the dependence of human life from the Earth' resources.

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The "Junior GeoScienze" pilot project: geo-oriented class activities for 4-5 years old students

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Keywords: Kindergarten, interactive learning, experimental work, field trip.

The study of geosciences is an important asset for students, because it ensures an adequate level of knowledge of our living planet. Such a study highlights the delicate balance between the natural system and the anthropogenic effect due to exploitation of the natural resources. In other words, the citizens who gather a good knowledge of the environment, very often, show an awareness of its long-term sustainability. Hence, subjects such as preservation of the environment, geological hazards, production of energy, water usage and tutelage should be taught to all students. This effort will likely better shape the society of the next future.

In order to fuel awareness and curiosity on the Earth, a pilot project is designed for the young students of the "Domenico Savio" kindergarten school of Potenza. Aiming at teaching basic concepts of Geosciences to four and five year old students, a series of lectures, laboratory activities and educational videos, and practical games are delivered to two different classes of the aforementioned school. Students are exposed to a variety of subjects, such as solar system, plate tectonics, volcanoes, earthquakes, etc., and perform simple experiments by either working alone or in teams. Practical exercises consist on rock type identification, fossil identification, build-up of small-scale volcanoes, and basic construction of home-made seismographer. All materials used in during practical exercises derive from recycling performed by both young students and families at home. A final class activity conducted in the field, by taking advantage of the beautiful geosites of Basilicata (ie. the Vulture Volcano) allow the students to show their ability to parents and friends.

In conclusion, the lesson learn after a two long experience teaching basic concept of Earth Sciences to young kids, and playing with them during practical exercises is the following: kids show a very good attitude dealing with uncertainties (we all know how much this ability is important in our everyday activities as geologists), and gather an appreciation for brain storming.

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The "GeoScienze" Project: an educational project for primary and intermediate school students of the Basilicata Region, Italy

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Keywords: Geosciences, geosites, interactive learning, primary school, secondary school.

Basilicata is a region of southern Italy with a diverse and fascinating geology. In fact, on a regular basis, it welcomes geologists from all over the world, who visit the area with the intent of studying its fantastic outcrops and peculiar settings. However, the population of Basilicata is frequently not aware of this important asset. "GeoScienze" is an educational project aimed at increasing awareness for the geological sciences amongst intermediate school students developed by ExtraGEO srl and University of Basilicata. The "GeoScienze" project is designed to deliver a series of theoretical lectures and practical exercises, with the intent of providing the basic tools of geosciences. Both lectures and exercises are thought by qualified, young teachers, who prepared the teaching and laboratory material under the tutelage of the academic professors. These young teachers not only share their passion for geosciences with the school students, but also fuel the curiosity of the students by involving them in the visit of the beautiful geosites of Basilicata.

"GeoScienze" includes several educational lectures delivered to primary and intermediate school students of Basilicata. One of the goals of the "Geoscienze" project is to share an appreciation for the environment and its geological significance by applying the ***I**nquiry **B**ased **S**cience **E**ducation* (IBSE) method. Students are exposed to several of theoretical lectures, educational movies, practical games and simple experiments such as rock type identification, understanding of the solid Earth system (i.e., plate tectonics, volcanoes, earthquakes), fossil identification, etc. In order to further stimulate the students, all lectures ends with a game played by groups of students. The final lesson consists on an field trip to one of the geosites of the Basilicata, such as the Vulture Volcano, the Lucanian Dolomites, the town of Sasso di Castalda, etc. There, students have the opportunity to observe and study rocks on outcrops, in order to decipher the principal attributes (i.e., composition, texture, sedimentary layering, tectonic structures, fossil content). The goal is to bring students to better appreciate the uniqueness of their local surroundings. To date, the project has been very nicely welcomed by the students. With the "GeoScienze" project, ExtraGEO srl and the University of Basilicata are confident to stimulate an interest for geosciences amongst teen agers who, possibly, will make a choice towards a career as geoscientists in the future.

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Cambiamento climatico, arretramento dei ghiacciai e desertificazione

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Keywords: cambiamento climatico, Antartide, scioglimento ghiacciai.

Lo scopo di questo lavoro è quello di valutare l'efficacia di un'attività didattica basata sul "*situated learning*" nella percezione del cambiamento climatico e riscaldamento globale del Pianeta nei nostri studenti, appartenenti a diversi ordini di scuola, in modo da stimolare la cultura della prevenzione come priorità strategica per un futuro sostenibile. L'inquinamento atmosferico ha modificato fortemente il clima del nostro Pianeta, determinando un aumento della temperatura media terrestre. Recenti studi scientifici hanno dimostrato che tale aumento ha avuto come diretta conseguenza lo scioglimento dei ghiacciai. I percorsi di *situated learning* che abbiamo proposto agli studenti hanno avuto come obiettivo quello di portare questi concetti, difficilmente esperibili dai giovani, sia perché relativi a luoghi distanti, sia perché basati su definizioni non sempre "*student-friendly*", ad un livello di realtà percepita e compresa perché vissuta dagli studenti sui loro banchi di scuola. Le fasi dell'attività sono state sperimentate in gruppi di studenti, di differenti regioni italiane, che si sono cimentati nell'osservazione diretta di immagini fotografiche relative al proprio territorio al fine di avere una visione di insieme dei cambiamenti morfologici che si sono registrati nel corso degli anni. Sono state create delle attività didattiche basate sul confronto di foto storiche con immagini recenti degli stessi luoghi. I percorsi di analisi delle immagini prima/dopo sono stati poi usati per attività di *peer-educatio*n tra gli studenti. Gli studenti hanno discusso tra loro sulle osservazioni effettuate, relazionando su quanto rilevato. Hanno compreso l'importanza del monitoraggio nella valutazione di ogni tipo di cambiamento, sia esso climatico che morfologico. Infine gli studenti hanno espresso il desiderio di proseguire questo percorso di osservazione e monitoraggio, del proprio territorio, nei prossimi anni. L'utilizzo di rappresentazioni del territorio locale si è rivelato uno strumento efficace nell'aumentare la percezione del cambiamento climatico negli studenti. L'obiettivo dell'attività del docente di scienze che affronta questi temi, cioè di rendere gli studenti consapevoli di quanto l'inquinamento stia distruggendo l'habitat naturale dell'uomo, dei cambiamenti climatici/ morfologici e dell'aumentata incidenza dei processi di desertificazione in numerose aree della Terra, può considerarsi raggiunto.

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Glaciological trails on the Italian mountains

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Keywords: Glacier, geomorphology, geotourism, climate change.

The Italian Geological Society and the Italian Glaciological Committee are working together to draw up and to print shortly a new volume of the "Regional Geological Guide" with the title "Glaciological trails on the Italian mountains". The guide is structured in two parts: the first chapters are focused on glaciology, geomorphology and climate themes; the second part, more substantial with pictures and maps, describes the glaciological trails chosen for the characteristics of the glaciers and for the geomorphological and geological features present in the territory, and also for the type of path. The glaciological trails considered are those already consolidated and known; it is the case of well-marked, sometimes circular, paths, with less difficulties, avoiding dangerous stretches on glaciers because they have rapid rates of change and have to be faced with appropriate equipment and only accompanied by experts.

Following the reinforced structure of the Regional Geological Guides published by SGI, for each trail, in addition to the detailed description of the geological and geomorphological evidence that can be observed at each stop, the necessary route information, scientific notes with studies and in-depth analysis on the glacier purpose of the journey and a selected bibliography have been listed.

The guide is aimed at a heterogeneous public, from students to researchers who are already dedicated to this topic, like hikers or people who are interested in the glaciers and their history. Therefore, with the necessary scientific style and, simultaneously, with clarity and a simple exposition, the guide considers 22 main Italian glaciers, distributed in all alpine regions: Piedmont (the glaciers of the Maritime Alps, Monviso, Alpe Veglia, the glaciers of the Sesia Valley, Belvedere Glaciers on Monte Rosa and Serrù Lake glaciological trail on Gran Paradiso), Aosta Valley (Pre-de-Bar, Miage, Lys and Rutor glaciers), Lombardy (Ventina, Fellaria, Sforzellina glaciers, and Forni glacier with the well known glaciological trail dedicated to the IGC), Trentino (La Mare, Careser, Adamello and Marmolada glaciers), South Tyrol (Val Martello and Vallelunga glaciological trails), Veneto (the Antelao glaciological trails), Friuli-Venezia Giulia (Canin and Montasio glaciers) and, finally, Abruzzo (Calderone Glacier).

The guide is presented as an educational and didactic volume and as a useful tool to help the reader discover the glaciers and to observe the geomorphological traces they left in the past and that can talk about their evolution.

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Teaching geosciences in primary school: an efficient training

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Keywords: geosciences, primary school.

The school has a main target: to ensure the success of all students. This ambitious goal may be pursued through individual curricula designed on the basis of the needs and attitudes of the students. This is the inclination of modern school, which tries also to offer a wide spectrum of learning activities. Teaching geosciences in primary school ensures a direct scientific approach to the objects of study. Teachers will treat communication with both educative and scientific aims. They will therefore not only present science topics from a theoretical point of view, but will also offer practical activities, that will be performed also out of school, for example during field trips. Lectures will occur at the same time with laboratories, and students will experience concrete activities with a mutual interaction between groups and with teachers. The involvement of young students in the observation of nature is aimed at steering them to a virtuous and conscious behaviour for the respect of the environment. This will contribute to the development of an environmental awareness, which will contribute later, when they will be adults, to the preservation of natural ecosystems. In the present work, we show some teaching experiences, which take advantage from the observation of the objects and reality to shed light on ideas and concepts developed directly by the young students. The students will learn about natural phenomena through the observation of nature and will play with the objects of nature. Natural environments will be perfect laboratories to play and encourage interest and curiosity avoiding passive learning, where students are always unwilling recipients of knowledge. Students will make their own discoveries that will be their best reward.

An Arduino based Seismograph for an educational multidisciplinar approach about Earthquake Hazard

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Keywords: educational program, Arduino board, seismograph, eartquake hazard.

We implemented an educational program (Saraò et al., 2016), based on the use of free software and low-cost open hardware, to improve high school students' scientific spirit and to excite curiosity about seismic-hazard issues and to engage them in the process of learning the best practices of seismic safety. This program was developed in some senior classes at the high school Liceo Paschini in Tolmezzo (northeast Italy).

Using an Arduino board, two ADXL345 accelerometers and open-source software, students was guided by their physics teacher and a team of seismologists, to create a low-cost seismometer able to record local strong motion.

To achieve their objective they made a minimal bash web server to send live data to the web and a html5 web application to visualize them.

Students used the seismograph to perform some simple experiments about wave propagation such as a sound speed measurement.

An "how-to" (instructional) guide to enable other students to reproduce the experiment was created and published on the web using GitHub.

Parts of the educational program was documented on the native language (italian) as a Wiki document, with some direct contribute from students.

We believe that this exercise is a good example of how earthquake issues can be taught through a multidisciplinary approach in subjects traditionally covered by scientific and technological disciplines.

Saraò A., Clocchiatti M., Barnaba C. & Zuliani D. 2016. Using an Arduino Seismograph to Raise Awareness of Earthquake Hazard Through a Multidisciplinary Approach. Seismological Research Letters, 87,1,186-192.

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An interdisciplinary educational program to explore the Sibillini National Park geodiversity

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Keywords: Didactic and science museums, teaching rocks, maps and landscape, Sibillini Mountain range.

Since 1991, the Science Museum of Camerino University is involved in exhibitions and educational activities dedicated to schools and general public. These activities contemplate direct interaction with the exhibits and interactivity, mediated by personal computers. Into the new "Sibillini Hall" of our permanent exhibition, the public can now explore a specific area of the Sibillini Mountains National Park using an interactive projector.

In this way it's possible to recognize the principal landscape elements: passing in front of the projection, public can discover an underlying image which reveals the subsurface, represented with various colors, each one corresponding to a different type of rock, like in a typical geological map.

Using multimedia technologies and rock samples "hands on" exhibition, we developed educational activities directed to primary and secondary school level students.

After this stage, which allows them to recognize the various types of limestones and marls belonging to the Umbria-Marche succession, and observe a real geological map, students can apply and test their new knowledge thanks to a didactic game. During the game, students can play individually and, using an orienteering compass and written instructions, they can find various rock samples placed inside the exhibition. At the end, students can identify each rock, know the geological diversity of the Sibillini Mountains territory and be encouraged to walk autonomously the mountain trails.

Deiana G., Galdenzi S. & Pierantoni P. 2013. Stratigraphic and structural features of the Sibillini Mountains (Umbria-Marche Apennines, Italy) pp. 497 - 520 - Geological Map of the Sibillini Mountains (Umbria-Marche Apennines, Italy) - Cross Section and Structural Scheme.

Un ponte tra la Scuola e l'Università per la divulgazione delle Scienze della Terra: l'esperienza del DiSTAR

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Keywords: Scienze della Terra, divulgazione, scuole, DiSTAR.

A partire dalla sua istituzione nel 2012, il Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR) dell'Università di Napoli Federico II ha nominato la Commissione Rapporti con le Scuole e Divulgazione il cui obiettivo è quello di curare i rapporti con le Scuole Superiori, al fine di stabilire una sinergia per iniziative congiunte a supporto della diffusione della conoscenza delle Scienze della Terra tra i giovani studenti della Campania. Tale obiettivo è in perfetta linea con le Indicazioni Nazionali della Riforma Scolastica che prevede, tra l'altro, che gli istituti scolastici ed i Dipartimenti Universitari possono promuovere congiuntamente attività di tirocinio, di formazione e di orientamento rivolti a studenti che in futuro intendono accedere ai Corsi di Studi Universitari. In questo ambito, la Commissione ha proposto il progetto "DiSTAR per le Scuole" che si fonda su attività seminariali e progetti di formazione e orientamento rivolti agli studenti degli ultimi due anni degli Istituti Superiori. A tale scopo è stato redatto un Depliant che descrive le attività offerte dal DiSTAR distribuito presso le Scuole e/o in occasione di eventi rivolti ad Attività di Orientamento e Formazione promossi dall'Ateneo Federiciano. L'attività seminariale si basa sull'offerta di un'ampia selezione di incontri su tematiche proprie delle Scienze della Terra, tra i quali i docenti delle scuole possono scegliere in relazione sia ai percorsi formativi programmati sia a problematiche strettamente connesse al territorio campano. L'obiettivo è quello di far cogliere agli studenti (e ai loro insegnanti) i legami tra l'attività del geologo e le discipline scientifiche di base dei percorsi scolastici. L'incontro, tenuto da uno o più docenti del DiSTAR presso la Scuola che ne ha fatto richiesta, è accompagnato da una presentazione dell'Offerta Formativa dell'Ateneo Federiciano nel settore delle Scienze della Terra. I progetti, invece, generalmente basati su un approccio multidisciplinare, prevedono percorsi tematici più articolati da modularsi secondo le esigenze didattiche di ciascuna scuola. Lo schema generale dei progetti, proposti da gruppi di ricerca afferenti al DiSTAR, prevede attività di formazione teorico/sperimentale (i.e. attività di campo e/o di laboratorio) da svilupparsi presso la Scuola e/o il DiSTAR con lo scopo di favorire una maggiore conoscenza, da parte degli studenti dell'Istituto richiedente, delle tematiche e del metodo di studio che sono alla base del Corso di Laurea in Scienze Geologiche. Per lo svolgimento dei progetti, inseriti nel Piano dell'Offerta Formativa della Scuola richiedente mediante stipula di un atto convenzionale, è prevista una durata da quattro a sei mesi da espletarsi nell'arco degli ultimi due anni di Scuola. La promozione delle citate attività nelle Scuole campane è svolta in stretta collaborazione con l'Area didattica della Scuola Politecnica e delle Scienze di Base della nostra Università.

CityQuest & "Caccia al...Tesoro dei Castelli", La nuova frontiera della divulgazione formato 2.0

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Keywords: CityQuest, Treasure Hunt, Geosciences.

Nell'ambito della manifestazione ScienzAperta 2016, ideata e promossa dal Laboratorio di Didattica e Divulgazione Scientifica dell'Istituto Nazionale di Geofisica e Vulcanologia, è stata proposta e testata una nuova tipologia di applicazione didattico-ludica per facilitare la comprensione degli argomenti scientifici, eseguibile su *smartphone* e *tablet:* la classica "*Caccia al Tesoro*" in versione 2.0 rivolta alle scuole di vario ordine e grado.

L'edizione di ScienzAperta 2016 si è aperta nella sede del Museo Geofisico di Rocca di Papa, storica sede dell'Osservatorio Geodinamico. Il museo si è mostrato il luogo ideale per testare un prototipo della versione *Caccia al Tesoro 2.0* e ha permesso l'incontro tra divulgazione scientifica e sperimentazione didattica.

La visita del museo insieme a un ricercatore/docente ha fornito ai ragazzi le conoscenze di base per il corretto svolgimento dei quesiti proposti dalla *caccia al tesoro.*

Il percorso museale si svolge attraverso sale espositive e si avvale di *exhibit* scientifico-divulgativi d'interesse geofisico, di "macchine" didattico-ludiche e di strumentazione geofisica storica e moderna per esplorare e approfondire, in modo efficace e stimolante, il tema della *modellazione dell'interno della Terra, attraverso le osservazioni geologiche e geofisiche.*

L'applicazione *CityQuest* è molto simile come grafica e funzionamento a quella di altre applicazioni utilizzate quotidianamente dai ragazzi. Sono stati proposti 4 quesiti ciascuno con titolo e descrizione. Ogni quesito fornisce cinque indizi, che facilitavano il raggiungimento della soluzione. Le risposte valide sono convalidate da un *Qrcode* e, la scansione del *Qrcode* corretto, permette l'avanzamento nella ricerca del *Tesoro dei Castelli*. L'interesse e l'impegno mostrato dai ragazzi sono stati molto incoraggianti. Sulla base di questa esperienza e in considerazione delle esigenze e necessità della scuola che si trova nella necessità di affrontare bisogni e specificità dell'apprendimento con specifiche e mirate metodologie didattiche, l'utilizzo di tecnologie coinvolgenti e facilmente acquisibili da tutti i ragazzi che, nel rispetto delle diversità, possono favorire lo sviluppo e il potenziamento delle loro capacità.

La Caccia al Tesoro 2.0 può essere inserita all'interno di un processo costantemente aperto a ricercare nuove situazioni di apprendimento e di relazione che permettano inserimento e integrazione. Il coinvolgimento emotivo e cognitivo del gruppo, si inserisce perfettamente all'interno delle nuove modalità di apprendimento: gli studenti, divisi in piccoli gruppi, affrontano in modo collaborativo, responsabile e solidale lo studio e ricevono valutazioni sulla base dei risultati ottenuti dal gruppo. Il raggiungimento di un obiettivo, "*Il tesoro*", facilita un atteggiamento cooperativo, anziché competitivo e dunque facilita le relazioni fra studenti "*diversamente abili*" e "*normali*".

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Teaching Palaeontology at school: a focus on fossils with a University-School-Museum Project

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Keywords: palaeontology, school, museum university.

The aim of this work is to experiment new ways to favour the approach of Paleontology in Italian schools, by making interdisciplinary links between science, history and geography with an approach based on hands-on and fieldwork approaches.

The research started with the observation of the minimal role of Paleontology topics in the school textbooks and its nearly absence in the national curriculum for primary and lower secondary school (grades 1-8). However, in spite of the little space devoted to it, the teaching Palaeontology is important as an introduction to multiple scientific thoughts and basic science concepts, as a tool to understand the geological time, the Earth environments in the past and their transformations with time, as a foreword to all the environmental sciences.

The project sees the collaboration among school of the Monfalcone area (Friuli Venezia Giulia, Italy), the Museum of Natural History in Trieste and the PhD program on Teaching Earth Sciences at University of Camerino. This collaboration is focused in particular to make aware the students about the paleontological aspects in the areas they live in, after a preliminary meeting with the teachers, during which topics, methods and calendar of the activities are explained.

A first presentation of the subject to the students is made, followed by a classroom interactive lab which takes advantage of the well evident local lithologies, used as building materials.

The students are invited to look for Rudists or Ammonites in the rocks in the school stairs and windowsills or outside, which prompts many points of discussion. This activity is followed by making fossils models using paper and glue, building three-dimensional models of environments and conditions where they used to live, creating sketches starring these animals. During the lab activities, the students can see and touch original fossils, which helps them make connections and better understand their 3D morphology and the link to the 2D as observed in the school windowsills. Interdisciplinary connections with other disciplines are suggested a Natural History Museum visit and a fieldwork experience in a paleontological area are carried out, followed by the project assessment, the teachers' questionnaires and a final evaluation of the activity.

The project (which involved 600 students) lasted the entire scholastic year and was built to give the teachers the competence, in the future, to carry it on in autonomy. Preliminary results evidence a strong interest by the teachers and good learning achievement and skills acquisition by the students.

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The Geology Project in the framework of the "Piano Lauree Scientifiche 2014-2016" (STEM studies sustain initiative, Ministry of Education)

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Keywords: Piano Lauree Scientifiche, Orientamento, Formazione.

The "Piano Lauree Scientifiche" is an initiative of the Minister of Education aimed to sustain Science, Technology and Maths studies. It is active since 2005, but only in 2015 Geology courses have been included in the grant system.

This is an important signal about the role of Earth Sciences in the framework of pure and applied science and technology.

The new "Piano" is structured in seven national disciplinary partnerships, including all the italian Universities where a BSc course is listed in their undergraduate prospectus. Then, the 29 University involved in the Geology Project share general and specific objectives for vocational guidance of incoming students, training of secondary school teachers, and initiatives in order to reduce the drop-out rate.

The description of these objectives can stimulate the discussion in order to improve the project during the next two years.

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The Story of Earth through the fun and entertainment: the playful aspect of fossils

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Keywords: fossils, paleontology, geological time, pedagogy, laboratory, learning by doing.

"*Culture is absorbed by a child through his own personal experiences, in an environment enriched by possibilities of work and discovery.*"

Maria Montessori

The educational project herein presented focuses on one of the most important topic for geosciences: Time.

The concept of time is not innate in man and so hard to grasp. Human beings can however, perceive and partially determine deep time through a succession of events.

Understanding "Geological Time" is very difficult because our Planet is way much older than anything experienced during our lifetime. For every one of us, trying to imagine more than 4.5 billion years with human standards is a difficult challenge. Earth History is such an extended interval of time that only through analogies we can try to quantify and understand the time elapsed between the various events on Earth history. In this context, the study of fossils is of great support, and knowing in which forms life has occurred over time, allows us to reconstruct the history of our planet.

This project intends to explore these important issues by means of two main practical activities, with the purpose of involving students in experiences that aim to inspire awe and curiosity, besides contributing to the acquisition of content and learning tools in a fun and playful way.

<u>The time clock</u>

The clock metaphor allows us to conceive the order of magnitude of geological time, a huge time span when compared with the length of human life and the evolutionary history of our species. The 4.6 billion years of existence of the Earth are proportionally compared to the 24 daily hours, condensing the major events in the history of life on our Planet, usually expressed in hundreds of million years, into hours. Each student builds a "prehistoric clock" enriched with drawings that symbolize the main stages of the history of life on Earth.

<u>The job of a paleontologist: dig and rediscover the past</u>

This laboratory activity provides a simulated paleontological excavation with the discovery, collecting, and realization of fossil casts. Students are guided throughout a regular procedure of an excavation by dividing into squares a delimited area, and in the following classification of their findings via comparison of samples and identification plates. Subsequently, after the molding of a plaster cast of the fossil previously found, the students, through drawings, will attempt to interpret the life appearance of the fossil organism.

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The Italian Earth's Science Olympiad: a reflection on results of first edition

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Keywords: students competition, earth science, science curriculum.

The Italian National Association of Science Teachers (ANISN) was established in 1979 and represents a corporation which aims at initial and long-life learning of High and Middle school teachers. One of the Association's purposes is enhancing the role of Science among new generation. For this reason the ANISN organize a national competition among students of high schools which to nurture young talents, but also to encourage pupils to challenge their skills about science.

The Italian Olympiads of Natural Sciences is divided in three phases: school phase; regional phase, national phase, students are divided in two categories: first two years (Biennio) and second three years (Triennio). The 13th edition was held this year: 500 schools participated along the national territory, while 3000 and 129 students participated, respectively, in regional and national phases. The winners of Italian competition participate in International Earth Science Olympiad (IESO) and International Biology Olympiad (IBO). This year triennio students could choose to take part in two different competitions with different topics: Biology and Earth Science. The decision to divide this two disciplines in different competition was taken in order to enhance the teaching and learning of Earth Science in the Italian schools, where they are generally poorly considered.

The National phase of Earth science Olympiad was held in May 2016 and we would presents the results of this first year of competition. This contribute aims to give informations about the syllabus of competition, the type of tests proposed and also to suggest some reflections about students performance in Earth Science tests. In fact, though the results in the international IESO tests are generally strongly positive, even if members of Italian team are younger than others, we have realized that, with the exception of basic contents, the level of students' competence still requires a long work of strengthening, as presented data can show.

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From nature to human needs: availability and use of geomaterials in Earth Sciences education

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Keywords: mineral commodities, geomaterials, technology, interdisciplinary connections.

Natural Science education in the secondary school follows a recurring logic: preliminary knowledges are enriched with new ones and with new perspectives. Not only description of phenomena, but also models and complex inter-relationships are considered. In Earth Sciences, one of the most important aspects is based on the interrelation between natural phenomena. According with the Italian Minister of Education guidelines (MG), the teaching activity in secondary school is expected to promote models on the inter-relationship between different factors that govern the same phenomena (or different phenomena). One of the goals mentioned in MG concerns the ability to highlight the potential implications of the themes in the everyday life. In this light, the study of modern Mineralogy is not based on the systematics only, as it was in the past, but it is expanded to the most common mineral commodities ("geo-resources" or "geo-materials"), their availability in Nature and the use of geo-materials for human needs and technology. New experimental findings can be the starting point to introduce, in a fascinating way, some key concepts suitable for the teaching activity in the last year of the scientific liceum.

Ceramic materials, cements and concretes, fire-resistant materials are all technological materials commonly used nowadays, along with natural and synthetic gemstones, or new materials able to replace asbestos represent some potential mineralogical themes to develop interdisciplinary connections, including also historical and economic concepts. Outdoor activities, carried out in collaboration with academic experts, allow students to observe active mines as source of geo-materials, but also of waste, developing the basic concepts of environmental sustainability.

The pursuit of all these goals requires, in order to maximize educational efficacy, the organization of projects that use geo-resource concepts in a larger frame, involving different disciplines, methodologies and activities.

An ongoing example is the Ossola Big History project, where High School students have developed a multimedia geotouristic guide to Ossola Valley. The guide focuses not only on the extractive industry of the valley, but also on its geological, anthropological, cultural and historical evolution, involving diverse disciplines, e.g. natural sciences, history, literature, arts, physics and philosophy. The outputs are an Android App, videos and power point presentations. Several activities allowed students to realize the integrated nature of knowledges in a complex system.

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Expedition to the South Pole: experience of the educational laboratory on polar sciences with primary schools

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Keywords: polar sciences outreach, laboratory on Antarctic, role-play technique.

The Polar Sciences represent an excellent topic for promoting new forms of collaboration between the world of research and the education. The outreach of the polar sciences, one of the branches of the Earth systems sciences tree, represents a unique opportunity, not only for its importance, multidisciplinary values and relapse of the polar researches, but, mainly, because it addresses and transmits ethical and social values as example of strong integration between human beings and extreme environments. In this frame the idea to communicate and to share the experience of the scientific research in Antarctica with the public and with the school is a challenge that a team of INGV researchers, engaged for many years in scientific missions in Antarctica, carries on with great enthusiasm within the several outreach activities of the Italian National Program for Antarctic Research (PNRA).The present work reports the experience of the outreach laboratory “Expedition to the South Pole”, realized in the frame of events organized by INGV and dedicated to the primary school. The educational themes developed within the laboratory concern the research in Antarctica, with particular focus on the human aspects, the geophysics and the progress of new technologies. The innovative aspect of the laboratory stands in the strategy to deal with Antarctica with an educational aim, proposing Antarctica as a natural laboratory, not only from a scientific point of view, but also as a laboratory of shared human experiences. The Laboratory is based on interactive methodology that uses the role-play and the experiential activities, enable the children to acquire knowledge on Antarctica (knowledge); to explore Antarctic characteristics as a natural laboratory and to experiment an emotional education through individual and team experiences (doing); to develop civics path linked to “sense of belonging and citizenship”, that will make the children aware that Antarctica does not belong to anyone but it belongs to everybody: it is a common and unique good (being). Based on several experiences realized with the schools, a video was made. The video is structured as tutorials for teachers who want to address the issue of Antarctica with their classes. During the presentation will be shown excerpts from the video to facilitate the sharing of this experience and to promote the production of other laboratories on Antarctica using the role-play technique.

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The teaching attitudes of the teachers inscribing their school to the Natural Science Olympiads

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Keywords: Natural Science Olympiads, teachers characteristics and attitudes.

In Italian secondary schools the subject called Natural Science includes Biology, Earth Sciences and sometimes Chemistry. By prior studies (Costa and Zauli, 1982) we know that in service high school Italian Natural Science teachers have mainly a degree in Biology and just a little percentage of them have a degree in Natural Science or Geology. On the basis of this premise, the aim of the research is to understand the didactical needs in Earth sciences teaching among a selected group of teachers.

We decided to interview the sampling group of teachers who enrolled their schools for the 2012 edition of the Natural Science Olympiad, which is a science competition dedicated to the high school students engaging the whole Italian country. A questionnaire was developed and tested before its use, than it was sent to the teacher as attached file. A first set of questions concern teachers' personal data, than a part of the questionnaire is dedicated to collect information in order to understand the way the sampling group of teachers have selected and have prepared their student for participating at this scientific competition. These information could be useful for better knowing teachers' attitude towards general science teaching and for comprehending the way their student get high scores at the school selection.

From the results emerged by the answers teachers gave to the questionnaire, it is possible to confirm that Italian Natural Science teachers are not so young and that they are mainly biologist. Moreover data reports also that the technological devices teachers mostly use in their classroom are the computers connected to the projector rather than the interactive whiteboard. At the same time by the results seems that teachers, even if they are supposed to be the most motivated ones, are strongly looking forward to receive more materials for preparing their Earth sciences lessons.

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Promoting Earth Science topics in the primary schools: future teachers at work in the university lab

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Keywords: Primary Educational Science, Earth Science, practical works, primary school, schoolchildren.

The increasing interest of the people in the environmental issues, often highlighted by the attention of the media to climate change effects, soil consumption, food production and natural potentially catastrophic events, need properly interpretations and explanations. Despite the requirement of a ‘scientific’ approach on these topics, Earth Sciences and Geology are often perceived as ‘difficult and boring’ topics also in the school.

Our objective is to form future teachers of primary schools on Earth Science topics, giving them some examples of a different, practical way to teach Earth Science to kids. Since 2015 a specific lab in Earth Sciences dedicated to university students at their penultimate year of study was organized within the course of Primary Educational Science at Università Cattolica del Sacro Cuore.

Students have been organized in groups of 3-5 for enhancing their collaborative skills and were asked to prepare three different practical works made suitable for their schoolchildren. The students had to organize themselves unifying the needs of simplification and narration with the rigorous subjects of the Earth Sciences.

The experiences regarded soil structure and evolution, water infiltration and relief formation. For the soil, they produced multilayer books mostly accompanied by stories told by exploring animals or by infiltrating drops or by the weathering bedrock itself. For the water behaviour in relation to granulometry, they set up practical experiences using bottles filled with gravel, sand and clay in which known volumes of water were poured. The different infiltration times and the ‘disappearance’ of water volumes were measured. For what concerns the relief, by means of coloured layers of salt dough a first horizontal stratification was followed by lateral tectonic shifts bringing to the relief formation. Later, gravitational processes and river erosion, evidence the different underground rock layers allowing the chronostatigraphic correlations within the landscape.

All these experiences are planned to be performed with cheap materials in order to be easily reproduced in the real primary school context. Moreover, all the experiences are related to the real world that children can know (the soil, the disappearance of water after rain, the landscape) and they lead to an a multidisciplinary approach (e.g. Geometry, Biology, time and measure ideas, scientific method). With our approach, we propose a method for transmitting Earth Sciences issues through practical experience also to very young children whose interest is stimulated and can start to understand very important elements of their environment.

From tree rings to climate and mountain landscape changes: an interdisciplinary approach involving music and mathematics

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Keywords: Tree rings, science communication, education, dendromusic.

The first level of secondary school pay particular attention to the interdisciplinary approaches applied to the different disciplines proposed to the students. Some learning difficulties for young students derive from the unconsolidated ability to the abstraction processes. As a result, referring to natural processes and easily observable elements from the everyday life facilitates not only the knowledge increase but also the construction of new capacities and the use of emotion dimension. Referring to the landscape changes and own territories is a useful starting point.

The aim of this project is to perceive climate variability in the recent past performing innovative representations of selected time series, namely mean monthly temperature and tree-ring chronologies, by means of sounds and graphs: the main goal is to represent the same objects stimulating different senses. Therefore, several disciplines meet under this approach: Earth Science and Biology as regards climate and tree growth, Physics and Music for what concerns the quantitative transformation of time series values in a sequence sounds and in a melody, Mathematics for what concerns classical visual representations of time series with a parameter over time (with xy diagrams and histograms), Informatics for the coordination of sounds and graphs or images.

For the transformation of the selected time series in sounds, we first selected the time series of June temperature anomaly from the HISTALP dataset (Auer et. al., 2009), and a tree-ring chronology from the treeline in the Veny Valley (Valle d'Aosta). For each value in the time series, a note was associated transforming the mean temperatures and the ring-widths centering the mean value of the series to the A note (440 Hz) and then applying proportional transformations of the values in the time series. In this approach, we respected the correspondence between high/low temperatures or large/narrow tree rings with high/low tones. The melody was then constructed starting from the selected sounds and adding also the component of rhythm according to the nearest 1/16 and giving 4/4 to the lowest value in the series. The high interdisciplinary approach here proposed may be effectively proposed in schools where a good cooperation between teachers is present, and can easily and effectively involve also students with disabilities, thus opening new approaches to teaching and learning science.

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GeoDidaLab: a laboratory for environmental education and research

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Keywords: environmental education, geoscience education, University third mission, didactic research.

The idea of proposing practical activities concerning environmental topics to the students of the district of Ivrea arose in the 90s by Adriana and Lino Judica, teachers at a local secondary school, who founded the laboratory as voluntaries. Ivrea is a town of the Metropolitan City of Turin in the Piedmont region (NW Italy), located on the road leading to the Aosta Valley. From the geological point of view, the Morainic Amphitheatre of Ivrea is one of the most famous in Europe; the traces left by the glaciers are today expressed by an extraordinary landscape.

From 1992 to 2013 the Permanent Environmental Education Laboratory (Laboratorio Permanente di Educazione Ambientale), located close to the San Michele Lake, was managed by the Interdepartmental Centre for Didactic Research and Teachers Updating (Centro Interdipartimentale per la Ricerca Didattica e l'Aggiornamento Insegnanti, CIRDA) of the University of Torino. Adriana and Lino, thanks to their experience as professors, their personal research and the cooperation with University professors, created from nothing a meeting place, a center equipped with simple materials for allowing their students to deepen the study of environmental sciences. Over the years, the laboratory became a landmark in the field of environmental education for schools by more than 50 municipalities in and out the Metropolitan City of Turin. It widened the educational offer with activities suitable for students from kindergarten to the University.

During 20 years of activity, the laboratory has conceived, designed, developed and implemented an educational offer composed by 19 interdisciplinary workshops ranging from the study of lichens and rocks to the use of microscopes for observing the waters of Ivrea lakes. Each activity has been designed to offer an integration to the school curriculum with research activities performed involving both students and teachers in chemical, physical and ecological investigations.

Starting from 2013, the Municipality of Ivrea entrusted the management of the Laboratory to the Department of Earth Sciences (University of Torino), with the aim of continuing and developing the previous one. During the first 3 years of management, new field activities have been designed, in order to connect more the reality of the Laboratory to the extraordinary geological area in which it is located. Together with Adriana and Lino, new relationships and agreements with the local community have been already created and are under construction, to plan new strategies.

The new name of the laboratory, now called GeoDidaLab, talks about a laboratory where teachers, University professors and students (at any level) can meet and share ideas about our Earth. It is a laboratory for scientific research, where new ideas can arise, thanks to an educational approach constantly opened to test new experiences. At the GeoDidaLab people can meet and perform research, education and dissemination at the same time.

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SoilQuest a Computer Class Role Playing Game

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Keywords: Role-Playing Game, Educational Game, Soil, Laboratorial Didactic, Hands On Activities, 3H: Head, Heart and Hands.

SoilQuest is a class Role Playing Game to teach Earth Science in First Cycle of Education Schools.

The educational technology is based on the idea of using language which is closer to pupils to improve the teaching/learning process. The game seems to be a perfect vehicle for education, even more when cooperative, since the acquisition of knowledge and enhancing skills now requires more actual approaches. The use of tablets, smartphones, social networks, etc. is more comprehensible and funny for young people compared to traditional media. The several roles allow everyone to enhance their own skills and are perfect for a full inclusion of Special Education Needs (SEN) students.

We have already realized two role playing computer games called GeoQuest (Maraffi & Sacerdoti, 2016) and GeoQuest Vesuvius (Maraffi et al., 2016) creating at the same time a Role Playing Engine (Autonomous system to use web educational contents in a classroom, Patent Pending NA2013A000048) which involves all students to the game through their personal mobiles or tablets giving a total interaction of the whole class to the game. The outcome of the class experimentation were excellent, both for didactic and educational results obtained (Maraffi & Sacerdoti, 2015).

This article is focused on our new computer class role-playing game based on *soil*, and specific for children 9-14 aged.

Students are guided through a virtual journey from the city across agricultural fields to the woodland. In the role game progression pupils, guided by questions and simple experiments (www.earthlearningidea.com), learn the different crossed soils characteristics: urban soil, wood soil, agricultural intensive and organic farming soils. The features to be investigated are related to: the soil color, the pedogenetic structure and soil fauna (Pennesi et al., 2016).

Different channels of perception will be stimulated with those activities and will be used multiple communication codes. In order to educate young people on environmental issues it is necessary to encourage diverse styles of learning: cognitive, emotional and pragmatic one through *the 3H*- Head, Heart and Hands.

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RISCHI IN CAMPANIA: un progetto formativo e di orientamento Liceo Statale "Eleonora Pimentel Fonseca" di Napoli - DiSTAR Federico II

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Keywords: Rischi in Campania, Laboratori didattici, Liceo Scientifico, Liceo delle Scienze Applicate.

Il Liceo Statale "E.P. Fonseca" di Napoli pone in primo piano, tra le sue finalità formative, l'acquisizione di metodi propri delle scienze e di competenze necessarie per seguire lo sviluppo della ricerca scientifica e tecnologica. Per assicurare l'acquisizione di un linguaggio specifico e la padronanza delle metodologie e delle tecniche relative, si propone di incontrare le realtà scientifiche presenti sul territorio (CNR, Università). Inoltre, in ottemperanza a quanto previsto dalle Indicazioni Nazionali della Riforma, la dimensione sperimentale è approfondita con attività svolte nei laboratori didattici della scuola e presso laboratori di università ed enti di ricerca, aderendo anche a progetti di orientamento. In quest'ambito, con il Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse dell'Università di Napoli, è in atto dall'anno scolastico 2014-15 una Convenzione di formazione e orientamento per lo svolgimento di un progetto sui Rischi in Campania. Il programma, che si sviluppa lungo due anni scolastici, è diretto a studenti di quarta e quinta classe del Liceo Scientifico e del Liceo delle Scienze Applicate e prevede interventi di docenti del DiSTAR presso la scuola, attività di campo e attività di laboratorio presso il DiSTAR. Il programma è articolato in un incontro informativo per la presentazione della Geologia come disciplina che dallo studio della Storia della Terra, indagata con molteplici mezzi ed approcci metodologici, trae informazioni sulla evoluzione futura di fenomeni geologici. Queste informazioni sono la base per la previsione e mitigazione degli impatti delle attività umane sull'ambiente, e la prevenzione dai rischi naturali. È illustrato, inoltre, il percorso culturale previsto su questi temi nei Corsi di Laurea in Scienze Geologiche della Federico II. Successivamente si tengono seminari tematici che affrontano problematiche legate al rischio sismico, vulcanico e idrogeologico. Sono previste attività di campo con escursioni ad Oplonti (NA) e al Somma Vesuvio, per quanto concerne il rischio vulcanico, e alle sorgenti di Sarno e alle opere di captazione dell'Acquedotto Campano per il rischio idrogeologico. Per il rischio sismico è previsto, quale attività laboratoriale, un esperimento di sismica attiva nel giardino del complesso di S. Marcellino (DiSTAR) volto alla misura dei parametri fisici dei terreni. Nell'anno scolastico 2015-16 si è concluso con successo il primo ciclo del progetto biennale. I risultati dei test comminati agli studenti alla fine di ogni anno del progetto hanno consentito di valutare le conoscenze acquisite riguardo alle tematiche trattate e di apprezzare l'aumentato grado di sensibilizzazione relativamente alle problematiche territoriali e al ruolo fondamentale del geologo nel controllo e nella gestione di un territorio esposto a rischi naturali.

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Promoting Earth sciences teaching-learning in the Italian schools: a great professionalism to improve skills and competence, an extensive cooperation for a network, passing through effective educational approaches

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Keywords: Earth sciences teaching/learning effective approaches.

In the Italian context, where Earth sciences are poorly considered in the education system and in the common thinking, to promote a widespread and deep-rooted culture of natural hazards it is a priority.

A brief analysis of the Italian education system shows that lack of a careful teaching learning across all levels of education, as request by the curricula issued by the Italian Minister of Education produces not only a lack of scientific knowledge, but mostly a worrying oversight of natural phenomena as part of the dynamics of the Earth and, accordingly, of the danger inherent in the geological evolution of the territory, needful for a responsible use of the environment.

It is possible to formulate hypotheses about the causes for which this happens: but the most important is to promote Earth science education in the Italian schools, to increase the interest of students towards geosciences, to find solutions for an increasing sensitiveness towards Earth science teaching-learning, to enhance teachers' competence in the use new and more effectives educational approaches.

Moreover, considering wealth and complexity of Earth science, in all its disciplinary plots, its links with many other scientific fields, it constitutes a remarkable tool to promote in students competences and skills, as request by Italian Minister of Education, the stakeholders of Horizon 2020 ad today society.

The path for the promotion of the teaching learning in Earth science should pass through the practice of active educational approach, attention to the personalization, the use of models and guidelines to produce tools and learning objects.

But it needs also a network of resources, building relationship between universities and schools, trying to bridge the gap between research and education, carrying their knowledge with the understanding of complex phenomena or proposing new discoveries useful to appreciate complexity of the discipline and recognise systems and flows among all different subjects.

And finally, it requests the development of a unique epistemology of the discipline, the promotion of Earth science as the discipline that more develops the ideas of system and complexity, the understanding of which is essential to promote scientific skills.

UNICAMearth: a research project on Geoscience Education

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Keywords: UNICAMearth Geoscience education.

UNICAMearth is a research project, started in 2011 at University of Camerino, with the aim to carry out activities in the field of education and dissemination of the Geosciences. The project raised with the idea that to increase the interest in the Geoscience studies among the young generations it is necessary to use modern didactic approaches, different from the purely trasmissive method, and that there is the need to support the teachers (mostly with a biology background) with materials and activities which allow a more appealing approach. The UNICAMearth group sees the collaboration of university researchers, museum operators and the PhD students in "Teaching Earth Sciences" at UNICAM, where a PhD program is dedicated to the science teachers involved in research projects in the field of Geoscience education (AA.VV., 2016). The activities carried out till now include both research and dissemination actions: seminars and laboratories in the schools for students, a summer school for teachers, the stage of the Italian team selected for the IESO, laboratories and field trips for teachers, a website dedicated to materials produced by the PhD students and freely accessible. The "Settimana del Pianeta Terra", the "Darwin Geologist Day" and the participation to science fairs, events and scientific conferences, makes the group very active at the regional, national and international scale. An evaluation of the impact of the UNICAMearth group activities up to now revealed that: 1) the interest and participation of the teachers to Geosciences activities has increased with time; 2) the organization of events, although varying as a function of the location is, contrary to the past, appreciated and asked for; 3) the interest of teachers for modern and useful online materials is high; 4) the teachers appreciate laboratory activites (IBSE, hands-on, PBL) especially when they can be easily reproduced in their classes. UNICAMearth also had an impact on the national scale, as evidenced by the spreading of the scientific sessions dedicated to the Geoscience education (e.g. Le Geoscienze a scuola, 2013, 2014, 2016) in the conferences organized by Geoitalia first, then SGI and SIMP, where the teachers have been encouraged to participate. This occurred especially thanks to the action of the PhD students-teachers. Last, the launch of EARTH-net (Camerino, 2013), a network to coagulate the interest of academics on the theme of Geoscience education and the collaboration with schools, allowed to start fruitful synergies and sharing of experiences among universities, museums, schools and research centers in Italy and abroad, which are starting to demonstrate its effectiveness with joint initiatives.

AA.VV. 2016. Le geoscienze a scuola. Paris E. & Pelfini E. (Eds). Rend. Online Soc. Geol. It., 40, 102 pp.

Urban geoheritage as a resource for Earth Science education: the case study of Milan

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Keywords: Urban geoheritage, education.

Fieldwork and field activities have been recognized as key experiences in fixing knowledge, acquiring competences and skills and in enquiring-based approaches in Earth Sciences education (King, 2006). Field experiences may be addressed to the discovery of geodiversity and geoheritage representing great opportunities for students to observe and analyze the landscape they live in (Magagna, 2016). Nevertheless many are the possible problems for outdoor lessons and activities related to traveling distances, economic implications, access limitations, insurances and in particular the annual hours for science lessons. In this framework big towns, small cities and also villages, differently inserted in the landscape, offer great opportunities for Earth Science education through an interdisciplinary approach including among the others: history, literature, art and also chemistry, physics and physical education. Urban geoheritage is becoming a new tool in cultural heritage and recent researches outlines the magnificence of Italian towns (Pica et al., 2016). Moreover urban geoheritage represents a great opportunity in teaching activities for different targets: children, students and also teachers. A practical example comes from the formation experience for secondary school teachers carried out by UNIMI among the activities of TFA (Training course for acquiring the qualification for teaching at the high school level). An itinerary in the city center of Milan, supported by a procedure for collecting lithological data observing buildings and street floors, becomes the instrument to move the attention from urban artifacts to the provenance sites (e.g., caves and mines) located all around the Northern Italy (and sometimes abroad) to open to the geology of the Italian Alps. A new "hydrological" itinerary inside the "Cerchia dei Navigli" (the ring of streets where navigable canals were present until early XX Century) is being developed and will allow to know the different hydrographic features of Milan during the past times, when fluvial geomorphology was more evident and when water ways were common. Moreover, subsurface data will allow the analysis of the contribution of superficial and ground-waters and of the works and infrastructures for water management in shaping the current urban landscape.

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Magagna, A., 2016, Educational tools for spreading knowledge of geodiversity and awareness of geoscience. UniTo, Unpub. PhD Th.
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The AIGeo role in developing new approaches and strategies for teaching Physical Geography and Geomorphology

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Keywords: Physical Geography, Geomorphology, Educational strategies.

The AIGeo (Italian Association of Physical Geography and Geomorphology) is a scientific *non-profit Association that aims at promoting and coordinating the researches in the fields of Physical Geography and Geomorphology. It also intends to encourage educational events for physical geographers and geomorphologists and to help the dissemination of environmental and landscape knowledge*" (i). The researches carried on by the AIGeo members cover various important topics of the environmental sciences and focus on scientific goals and on the development of educational strategies and didactical applications as well. These latter aims also to disseminate the most recent scientific results, encouraged by Horizon 2020 programme too.

The communication of scientific novelties fits well with the indications included in the Ministerial National Guidelines for secondary schools (2nd level). These guidelines (ii) underline the importance of a phenomenological and descriptive approach, based on landscape observations during the first two-year period. In this perspective Physical Geography plays a key role as far as Earth surface processes are concerned. The role of Geomorphology becomes more relevant in the following two-years period, when Earth Sciences need to be linked to the local geographic context. The mentioned disciplines (chemistry, physics, mineralogy, petrology, volcanology, seismicity, tectonics) to be linked each other found the required correlation in the landscape genesis and evolution. Finally, in the fifth year, when complex phenomena have to be faced, Physical Geography and Geomorphology allow to analyze current problems as climate change, the consequent hazard and risk scenarios and the environmental resources management underling the social function of Earth Sciences. These topics are some of the cores of geomorphologists' activities that are going to be translated with an educational perspective.

In our work Geoheritage and climatic change impacts have been considered as possible starting point for educational applications and fieldwork activities not only dedicated to the secondary school (2nd level), as here referred to, but also to younger students and future teachers TFA (training courses for acquiring the qualification for the profession of teachers). The long experiences in textbooks realization acquired by some AIGeo researchers is constantly supporting both teachers and researchers themselves in looking for even more effective and innovative approaches for Earth Science education.

(i) http://www.aigeo.it/en/
(ii) http://archivio.pubblica.istruzione.it/riforma_superiori/nuovesuperiori/index.html

Promoting innovation in Geoscience education: the experience of Geology Courses of the University of Perugia

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Keywords: Geoscience education, innovation, augmented reality.

Geoscience in Italy is facing a serious challenge due to the fact that the number of students registering to geoscience curricula is constantly decreasing and the ratio of registered/graduated students is not encouraging.

The inclusion of geosciences within the disciplines funded by MIUR in the context of the "Piano nazionale Lauree Scientifiche" (PLS) provides an interesting opportunity in the attempt of mitigating these alarming trends.

Here, we report about the new activities developed by the Geology Courses at the University of Perugia. These were organized on two different fronts: 1) the development of a new and innovative web site (http://geo.unipg.it) and 2) the organization of a unique interdisciplinary laboratory for geosciences: the TerraLab Explorer.

The web site has been designed in order to be easily accessible through mobile devices and contains many interactive contents to inform students about geological processes and the fascinating life of geologists. The site also hosts many outstanding contents of augmented reality that students can experience using their own mobile devices: the "Augmented Reality Newsletters". These are about the major topics in geosciences including plate tectonics, earthquakes, volcanoes, fossils, minerals, etc., and can be downloaded and used by students and educators in the classroom or at home.

The TerraLab Explorer is intended to host students and educators from the high school (and university students) for developing laboratory experiments following the "learn-by-doing" approach. Among the proposed experiments are the Augmented Reality Sandbox for simulating Earth's surface processes, the study of transport of Earth's material using a rock tumbler, macro- and microscopic observations of rocks, fossils and minerals, and 3D printing of geological objects. In the TerraLab Explorer students and educators can perform a number of experiments, extract data, validate hypotheses, and test their knowledge.

These new approaches allow students to participate actively in learning, inquiry, group discussion, and analysis so that they become familiar with the process of science instead of simply memorizing vocabulary and formulas. Through our pedagogical approach, even those high school educators with minimal background in geology can motivate students to understand the importance of learning about geological systems. Further, students from the high school can benefit from the proposed interactive experiences to evaluate on a solid ground the opportunity to register for geological courses at the university.

Preliminary results indicate that the above activities can improve the opportunity for high school educators and students to communicate face-to-face with scientists and teachers from the university. We also noticed that the combination of conventional and modern teaching and training strategies can improve significantly students' analytical capability and acquiring knowledge about geosciences.

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Charles Robert Darwin Geologist: a Learning Sequence about Volcanoes and Earthquakes

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Keywords: Learning sequence, Volcano, Earthquake, Darwin.

It is a matter of fact that - in every schoolbook - Charles Darwin is mentioned for the Theory of Evolution but not as a geologist. We recovered this forgotten prospective of the scientist in a learning sequence about volcanoes and earthquakes.

Volcanoes and earthquakes are fascinating matters for pupils but they can't make direct experience of them. So we can use the ICT (Information and Communication Technology), namely Google Earth, Fusion Table and web resources on a multimedia board, to please their curiosity. Our sequence starts asking pupils of the third year of middle school to draw and describe a volcano. After sharing answers, pupils compare their drawings with images of real volcanoes and discuss the differences. They realize on their own that a difference of erupted materials can determine a difference of shape. By experimenting magma flow behaviour through analogue materials, they understand the role of the viscosity in building the volcanic edifice. The pupils use water, oil, peanut butter and tomato ketchup (Baker et al., 2004), also with couscous or sand, along an inclined plane, and warm honey to show the temperature dependence of viscosity. To introduce the topic of earthquakes pupils watch a video about the earthquakes of Messina in 1908 and then discuss about the effects of earthquakes. Reports from Darwin's travel on the Beagle (Darwin, 2002) for the earthquake of 1835 at Valdivia and the effects of tsunami at Concepcion in Chile and articles about earthquakes of 2010 and 2015 in Chile are shown. In this occasion the class discusses about the importance of mapping past earthquakes to increase awareness of the seismic hazard. They examine simple models of waves to understand how the seismic energy propagates within Earth.

At the end of the education sequence, a virtual travel with Darwin on board of the Beagle furnishes a feedback on their learning. The teacher prepares a form of Fusion Table (a free Google app that allows geolocalizing information on Google Maps) with Darwin's places, their coordinates, a little description and picture of stop-over of Beagle, Darwin's text, queries and bibliographic links. Pupils click on locations in Google Maps where Darwin observed a volcano eruption or felt an earthquake. As a consequence, a window with research material opens and they have to answer queries, using the web resources and what they learned in class, experimenting a motivating and stimulating use of ICT.

Baker D.R., Dalpè C. & Porier G. 2004. The Viscosities of Food as Analogs for Silicate Melts. Journal of Geoscience Education, 52, 363-367.
Darwin C.R. 2002. A Naturalist's Voyage Round the World. It. trad. Editore Giunti. Firenze.

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Dissemination of the geological subjects through the language of theatrical arts

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Keywords: Dissemination, Geosciences, theatrical arts.

According to recent legislative and ministerial standards, teachers are required to change the way of "doing school" and to put "emphasis" on the needs in order to build a coherent and unified profile of cultural meanings" through dialogue between the different disciplines, The National Guidelines regarding OSA (specific objectives of learning) according to the European directives based on the "knowledge society", recommend to improve interdisciplinary connections. The predominant linear path of disciplinary knowledge found in text books, enables a "schematic" mental state instead of leading to the "ability to connect", which could facilitate the development of complex thinking skills. This methodology resulted, over time, in a superficial knowledge that has led to the permanence of "misconception". In high school "laboratory practical experience [...] are promoted as a psychological mode, organizational, methodological, didactic, to have knowledge" (professional skills). The proposal of this research is to experience a laboratory of creative writing with a flipped classroom: the lectures and assignments are turned upside down. In the classroom there will be a debate on the personal studies. These are the questions that will be asked: • Is the theatre "foreign" to science? • Is it possible to promote scientific knowledge? • Which form does provide a privileged access to science? • Does this tool indicate the link between 'two cultures'? We've analysed the precedent experiences and these are the results: • Weaknesses: it's possible to put together theatre, science and school to get scientific education but it can also happen that one of these elements loses a part of its peculiarity. • Strengths: lots of experiences in the school can be compared; theatre promotes a context of collective experience. Our proposal was to produce a training module. We've realised a form for the scientific script with didactic value titled "The man and the mountain: the Mont Blanc". The procedure provided for: • The analysis of pedagogical needs; • The presentation of the cases; • The analysis of the misconceptions or prior knowledge; • The selection of the scientific concepts we focused on; • The application of the acquired knowledge. The role of the teacher changed: he researches the material, writes the script with students, improves storytelling, assesses progress. Teachers from different disciplines must work together, creating the script with the students, who will be assessed during the creation of the scene and the dramatization, focusing on the show and the script.

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Glacial environments in Earth Science education: Textbook chapters characteristic, teacher's approach and student responses

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Keywords: Earth Science Education, Glacial Environment, Earth Science textbooks.

The changes introduced by the last Reform (2010) involve changes in teaching in term of programs and approach to arguments. A selection of twelve Earth Science textbooks (the most common in the biennium of scientific and classical high schools; Sturani 2016 being printed) has been used for an analysis of the chapter(s) dedicated to glaciological thematics. The twelve extracts have been analyzed as regards i) the percentage of pages and pictures dedicated to the subject respecto to the total of the book, ii) numbers of pages and pictures dedicated respectively to glacial processes and glacial landforms, iii) the geographic location of subjects in the photographs and iv) the presence of references. Through an on line questionaire dedicated to the teachers it has been investigated whether, and at which level of detail, teachers approach and discuss glaciological themes. We've analyzed if and when the cases are presented as related with climate change and hydrological cycle. A sample of students from different classes of the same school (traditional scientific high schools), have been selected for a comparison with regard to chapters taken from twelve textbooks. The students have been given a questionnaire in order to investigate their preferences with reference to the differences in chapters approach and structure, the comprehension of the topic and the following study phase. In addition to this, suggestions for an easier approach to the glacial environment have been requested and at the same time information has been collected concerning the specific glaciological elements studied with their teachers. The chapters characteristics identified as the most influencing the effectiveness of an educational textbook are: the division into text paragraphs, a clear and synthetic exposure and the use of images that help to understand the concepts. The most requested properties are the inclusion of summaries and final questions. The obtained results have been compared with the ones obtained from university students of Communication and Educational Laboratory of Natural Sciences and from a group of adults enrolled in the training for news teachers (TFA). These groups have privileged an increased complexity of the chapters and the presence of final unnecessary questions. The survey on teachers showed that 43% of them have included the study of glaciers in their program. The majority have preferred the hydrological cycle. More than 80% of the teachers don't make a speech on climate change, as they consider themselves not sufficiently prepared on the matter.

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A teaching experiment on the learning of concepts related to geological time: first results

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Keywords: Geological time learning, misconception-based teaching, constructivist approach.

Geological time has been widely recognized as a pivotal concept in the teaching of geology and other science subjects characterized by historical dimension, including evolution and cosmology. Concepts related to geological time have been analysed in the light of cognitive research, and the understanding of these concepts has been explored by many authors since the pioneering studies of the 1980s.

Despite an extensive record of literature on geological time, only a minority of published researches deal with interventional studies, none of which are known in Italy. For this reason we planned an experimentation on the learning of geological time in a sample of Italian students after the completion of the 1st instruction cycle. We asked wondered a short teaching activity could improve the understanding of geological time concepts and whether a constructivist approach based on misconceptions could be differently effective than a more traditional cognitivist approach.

A randomized case-control trial (misconception-based vs. cognitivist teaching) extended over two teaching sessions and included the following steps: a pre-test, an interactive lecture and a post-test. Two months later a third delayed test was given to assess the long-term retaining of the learned concepts. The lecture focused on the history of Earth, with the addition – in the experimental group - of spatial models and questions aimed at eliciting cognitive conflict about the addressed misconceptions. The assessment tool was built drawing the items from published research questionnaires, translating and adapting them to the national school context. Every question addressed one or more of these four basic concepts: succession, duration, dimensional scale and basic knowledge of stratigraphy principles. The sample consisted of 298 ninth grade students of *liceo* high schools located in Friuli Venezia Giulia, randomly allocated to the experimental or to the control group. Both in the experimental and control arms of the trial test scores displayed a significant improvement after the teaching activity, despite its short duration. Among the students who obtained equal or better scores in the post-test, the experimental group performed significantly better than the control group. The results therefore suggest that even a short intervention on geological time may improve the understanding of the concepts related to this topic among 13-15 year students. The higher scores recorded in the delayed test in comparison with the post-test – without further teaching of geological time in the interval – raise some questions about a possible synergistic effect following the teaching of other subjects (history, maths) or the physiological cognitive development of adolescence.

Further research with a longer teaching activity would be advisable to better understand the effect of the different approaches (misconception-based vs. cognitivist) tested in this study.

School activities at the Cristalli ai raggi X exhibition: the gypsum of Vezzano sul Crostolo (Reggio Emilia, Northern Italy)

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Keywords: X-Rays, Gypsum, Vezzano sul Crostolo.

2014 was declared the International Year of Crystallography by the General Assembly of the United Nations, after 100 years from the awarding of the first Nobel Prize for the discovery of X-ray diffraction by crystals. On this occasion, the Department of Chemical and Geological Sciences of Modena and Reggio Emilia University (Italy) and its Museum "Gemma 1786", organized an exhibition named Cristalli ai raggi X (Modena, 24 Jan. – 29 Mar. 2015). The initiative involved the cooperation of many public and private partners and the active participation of twenty schools of different types and levels. An innovative aspect was the planned participation of high-school students to the fifty collateral events organized during the exhibition. The main purpose of Cristalli ai raggi X was to introduce non-specialists to the world of crystals and their properties, and to show how crystallography plays a role in the development of scientific disciplines like chemistry, physics, earth sciences, and even biology and medicine. This science exhibition highlighted in a simple and understandable way the links between crystals, science, technology, art, history, and society. In addition to a wide range of scientific materials (minerals, precision instruments, technological applications), the event also included a variety of cultural and artistic items. The display ended with the appreciation of 9,000 visitors and a hundred of guided tours for regional and extra-regional schools.

A third-Year Middle School Class of Vezzano (Reggio Emilia) took part in a specific project about gypsum and its importance in the local history of the town. According to the Middle School's and University's teachers, the class inquired about local rocks and minerals, expecially about the Messinian Evaporitic Formation surrounding the town, then researched in the mining history in Vezzano (Agosti et al., 2004) and in simple physical and chemical properties of gypsum, like hardness, density, water presence in crystalline lattice. Finally the class explained to the present people the result of the research in mining history by slides and the properties of gypsum with simple experiments. This project showed some interesting learning essentials points, like the collaboration between different educational institutions, the laboratory approach to a scientific theme, the implementation of several skills (information research, adequate explanation, management of own emotions, team collaboration).

Agosti G., Ferrari S., Lugli S., Masini S., Scacchetti M. & Vacondio L. 2004. Le cave di gesso nel comune di Vezzano sul Crostolo: 700 anni di storia. Quaderni di storia vezzanese Sine Tempore, 3.

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Earth Science nell'attività della Sezione Campania A.N.I.S.N

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Keywords: observation, experimentation, deduction, investigation.

Earth Science is part of a group of discipline that, in our Country, is called Natural Science. At present this name is disused taken over by Environment science and Biology which has flown up and started studying it in depth and expanding the molecular complex of the discipline.

Between Natural Science, Earth Science and particularly Geology altogether have requirements and therefore also working and learning survey, typical of the so-called experimental science. This denomination includes an experimental or laboratory method which is the specific disciplinary. It foresees a real approach, based on observation and on experimentation.

Our association has practiced this method by involving teachers first and then students of various levels. We think a real observation approach (to learn observation), confrontation, consideration, experimentation of facts and natural phenomenon in every school levels, starting from primary school produces a significant and not superficial naturalistic formation. Learning is based on cooperation between the teacher and among students in various groups of the class and makes all to participate and to facilitate interaction and sharing. Moreover, close to nature stimulates the emotional sphere, which has much importance as far as consideration and concepts assimilation discipline is concerned.

In this process the teacher makes use of intermediary help which is nature itself; first of all making excursions on territory and then theatre performances, songs, exhibition, plastic models, and any other product capable of stimulating interest and consideration on various topics. In the end experience, relationship among all subjects of the class group will get at the final phase of learning which is knowledge organization.

In Italy at present A.N.I.S.N. is spreading the IBSE method based on investigation.

Attitudes of pre-service teachers in planning and scheduling geo-field trips at secondary level: a case study

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Keywords: Earth Science Education, outdoor learning, field trip, pre-service teachers.

Field trips are considered very powerful methods of learning in Natural Sciences and Geography but it is in the domain of Earth-Science learning where they play a core role. Since field trips represent a way to integrate classrooms to the real world, benefits from field activities are numerous, from a deeper comprehension of knowledge to the acquisition of specific skills and abilities (Orion, 1993, 2003).

Despite this, recent studies evidence a general decline of field activities in Earth-Science courses for primary and secondary schools. Lack of time, increasing costs, logistics and strong safety protocols are some of the factors that strongly demotivate teachers to plan field activities. Nevertheless some authors pointed out that, among others, an important limiting factor is (depend on) “the unfamiliarity with conducting field trips and the lack of curriculum materials relevant to field trip” (Orion, 2003). Considering what explained above, fieldwork training should be an unavoidable step in the Earth-Science program of pre-service teaching. Only a small number of studies focus on the attitude of pre-service teachers in fields activities (e.g. Costillo et al., 2011) but there are no reports giving an idea of the effectiveness of the training program on novice teacher’s skills and abilities in scheduling, managing and conducting field trips. For this reason the basic aim of this research is to measure - in a sample of Italian pre-service secondary teacher science program (TFA/2015)- both their prerequisites and previous attitude towards fieldtrips activities or the effectiveness of the program in enhancing teachers ability in planning field trips. A first analysis of the fieldtrips proposed by the novice teachers evidences difficulties both in the organization and in the teaching approaches, greatly conditioned by previous personal experiences. In most of the cases a traditional “teacher centered” approach is adopted instead of an inquired based one. Even if the analyzed sample is small, this work allows a preliminary overview in the context of a more complex evaluation.

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SESSION S38

Open Poster Session

CONVENER

Lorenzo Fedele (Università di Napoli Federico II)

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Is it possible to optimize the traditional classification scheme of ultra-alkaline rocks by means of combined statistical methods?

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Keywords: Ultra-alkaline rocks, Rocks classification, Petrogenesis.

The rare rocks-association of carbonatites, potassic melilitites, lamproites, lamprophyres and leucitites ("ultra-alkaline" *sensu* Le Bas, 1987) have unique modal and chemical features that make impossible and misleading their grouping on a unique classification diagram. Many schemes of classification for igneous rocks are based on mineralogical and/or geochemical variables which vary with differentiation processes. However, the ultra-alkaline rocks often do not comply with common petrogenetic processes. The Recent Italian ultra-alkaline association occurs along the Apennines with monogenic volcanoes and the Vulture volcanic complex and along the Tyrrhenian coast in caldera and strato-volcanoes. Therefore, a correct classification of the ultra-alkaline rocks, would be very useful to define unique geologic pattern in the Italian area and in general for other similar occurrences worldwide. As they are not consistently classified by IUGS method (e.g. Tappe et al., 2005), they have been studied using various statistical methods. The RHA method is based on three parameters (Krasnova et al., 2003). The first parameter (Rank) is the rock geochemical composition or mineralogical composition (mode/norm), ordered by atomic abundances or modal/normative volumetric percent. The other two parameters (Entropy and Anentropy) are used to discriminate rock types having the same rank formula. The second statistical approach employed is the Principal Component Analysis (PCA). PCA allows the definition of new latent variables (PC_n) based on geochemical compositions through linear combinations of the major oxides. The number of new PC_n is less than or equal to the number of original variables. Both statistical methods discriminate groups of litho-types. In particular the PCA produced grouping of different ultra-alkaline rocks, having a direct correspondence with IUGS nomenclature but on chemical base. While using RHA method it has been possible to define a series of different groups of heterogeneous ultra-alkaline rocks, not related to current taxonomy but to petrogenetic system. As a whole, a simple chemical ternary classification diagram has been determined that outlines a possible genetic link between different rock types which may be used coupled with to the taxonomic IUGS classifying schemes (Ambrosio, 2016).

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Hazard minor elements in asbestos and other fibrous minerals contained in the Gimigliano-Mount Reventino Unit (Calabria, South-Italy)

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Keywords: minor elements, serpentinite-metabasalt, asbestos.

In the meta-ophiolitic sequence belonging to the Gimigliano-Mount Reventino Unit (GMRU) serpentinites are associated with amphibole asbestos. In order to assess the environmental impact of these deposits, many asbestos-bearing sites were studied in detail because long-term exposure to asbestos is known to cause pulmonary diseases. Previous literature has allowed to characterize both asbestos and non-asbestos fibrous phases contained in serpentinitic/meta-basalts rocks, and-to discriminate between the three serpentine pseudo-polymorphs. Serpentine from GMRU were often intergrown with amphibole asbestos which showed two main varieties: tremolite and actinolite. More recently, attention was also focused on those sites where human activities may potentially disturb asbestos bearing rocks (Bloise et al., 2016). As far as the chemical composition is concerned, in addition to its major structural elements, asbestos contain various minor cations (e.g., Cr, Mn, Ni) that can occupy the octahedral sites. The presence of these foreign cations, even if to a limited extent could play an important role in pathological effects. Indeed, some researchers claimed that a probable role of asbestos fibers in producing disease could be only a passive role as ~~a~~ minor elements carrier. In this scenario, in the present study a more detailed analysis of minor elements present in 20 asbestos samples of the GMRU was performed by EDS-SEM and AEM-TEM.Results have shown that Cr was present in a very high amount in almost all asbestos analyzed. The highest content of Cr is present in fibrous antigorite (1.2 wt.% as Cr_2O_3) followed by polygonal serpentine (1.1 wt.%), chrysotile (0.85 wt.%) and tremolite (0.02%). This finding is in accordance with the results of a previous study (Apollaro et al., 2011) reporting that asbestos hosted in the serpentinitic/meta-basalts rocks of GMRU was an important, active source of dissolved Cr. Mn was mostly concentrated in actinolite (0.8 wt.%; as MnO). Ni was scarcely present in chrysotile samples whereas it was predominantly found in tremolite. It is generally accepted that none of the theories alone can adequately explain the pathogenic mechanism of asbestos. These data suggest that the cytotoxicity of asbestos may be also related to the minor elements present as impurities in their structure.

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High resolution seismic imaging of fluvial environment from the Summer School in Exploration Seismology 2015 acquisition field

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Keywords: High resolution exploration seismology, fluvial environment, Campanian Appenines.

The shallow high resolution exploration seismology is increasing its utilization into many geological fields. For this reasons always more students are interested to improve their seismic knowledge and pursue careers in exploration seismology. The Summer school in exploration seismology 2015 was organized by the National Institute of Geophysics & Volcanology (INGV) and by AMRA (Analysis and Monitoring of Environmental Risk), and it was held between August 2 and August 8, 2015 at the INGV section in Grottaminarda (Avellino, Italy). The Summer School purpose was to enhance students' knowledge by going beyond a standard classroom-based applied seismology curriculum, by a full-immersion into a typical and tight industry-standard high-resolution exploration seismology project to be completed in seven days. During the course, a group of 13 students, together with two experienced supervisors collected 1.4 km of high resolution seismic data, using the vibrational source IVI MiniVib and an array of 7 seismographs GEODE. Participants were actively involved in all phases of the project (from data acquisition to processing and preliminary interpretation & presentation). The seismic dataset was acquired in two days, the first was useful for the students to learn how to operate with the seismic instrumentation and the second day the field operations were managed only by the students. In this manner the class focused about field data acquisition and solved typical survey trouble. The investigated area is located in the Fredane Stream valley, within the Campanian Appenines between Gesualdo and Villamaina villages. Data were collected in the valley along its major axis, over a crooked line, using a large array composed by by 168 vertical geophones with a 4.5 Hz eigenfrequency. Sensors were spaced each 5 m allowing an array aperture of 835 m and source move-up was 10 m. The data processing was performed through the commercial software Landmark ProMax 2D; a standard processing flow was applied to the data and allows to image the river alluvial deposits, distinguishing different depositional facies, and reach the carbonate basement.

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New field evidence for an exhumed Jurassic paleoescarpment tract of the Mt. Pennino structural high (Northern Apennines, Italy)

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Keywords: Jurassic, Umbria-Marche basin, pelagic carbonate platforms, Calcare Massiccio, submarine paleoescarpment.

A geological mapping on the 1:10,000 scale in the Umbria-Marche Apennines was performed in a 50 km² wide area, stretching from Fiuminata to Nocera Umbra. A PCP/basin depositional system, the product of Early Jurassic rifting, is comprised of a condensed pelagic carbonate succession, typical of structural highs, and a pelagic carbonate/siliceous/marly succession typical of hangingwall basins.

While condensed pelagites overlying the drowned peritidal limestone of the Calcare Massiccio Fm. have long been known at Mt. Pennino, sedimentological evidence for restoring the depositional architecture of the structural high and adjacent basin has never been deeply investigated. New field evidence suggests the existence of an exhumed submarine paleoescarpment, which was mapped in detail for the first time and is discussed here.

The Pennino structural high covers about 5 km², and consists of a flat top dipping 30-40° towards W and NW. On the PCP-top a pelagic condensed succession is represented by the Bugarone Group (Pliensbachian-early Tithonian), resting on the Calcare Massiccio Fm. through a slight angular unconformity.

The eastern slopes of Mt. Pennino are bounded by a NNW-SSE and N-S trending thrust developed during the Neogene Apenninic shortening. Along the thrust the Maiolica Fm. overrides the calcareous-marly Meso-Cenozoic succession toward ENE.

The western slopes display instead the preserved portion of the paleoescapment. The unroofed paleosurface of the footwall-block Calcare Massiccio is marked by cm-across siliceous nodules, a diagenetic overprint due to burial under the onlapping Jurassic chert-bearing pelagic units. The paleoescarpment strikes sub-parallel to the Mt. Pennino thrust, and dips toward E-NE. On the NE side the paleoescarpment hosts unconformable patches of condensed epi-escarpment deposits, made of brown and white pelagites referred to the Bugarone inferiore Fm., rich in *Protoglobigerina oxfordiana*, and to the Bugarone superiore Fm. with Tithonian ammonoids (*Aspidoceras* sp., *Lytoceras* sp.) and aptychi. Based on these ages, this paleoescarpment tract must have formed during the immediately post-faulting (Sinemurian) to early Bajocian interval, and apparently experienced no episodes of erosional retreat for tens of million years, until at least the end of the Jurassic, testifying the paleotectonic stability of this sector during the post-rift.

From a structural standpoint, an interesting feature is the ‘unnatural’ downlap of the W-dipping Maiolica Fm. strata against the N-S trending of Calcare Massiccio paleoescarpment, before changing their dip to the E to form the forelimb of the anticline. These “odd” angular relationships can be interpreted as the result of buttressing processes during Neogenic compression as the paleoescarpment itself is not folded. The Mt. Pennino high bears therefore evidence for a control exerted by the inherited pre-thrusting structure/submarine topography during Apenninic shortening.

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The Geo-Pedo-Bio Fingerprint (GPBF) of the "Aglianico del Sannio". A multidisciplinary study

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Keywords: Geo-Pedo-Bio Fingerprint (GPBF), Vineyard Landscape, Soil.

This study represents the first in-depth multidisciplinary research aimed at identifying the Geo-Pedo-Bio-Fingerprint (GPBF) of the "Aglianico del Sannio". The investigation involved geologists, biologists and soil scientists, that synergistically produced new relevant data, such as: mineralogical and chemical soil analyses, isotopic signature (87Sr/86Sr) of soil and wine, genetic characterization of Aglianico clones and their expression analysis at pre-veraison stage as well as thematic maps characterizing the vineyard landscape of Sannio.

To this end, a medium-scale soil-landscape map of of the Sannio Beneventano vineyard area was produced, based on the reprocessing of data resulting from previous, long-term researches. For three very relevant vineyard landscapes, an additional, detailed soil survey was carried out. The surveyed soils were analyzed in the laboratory and classified, according to the WRB.

Strontium isotope ratios (0,7085-0,7087) consistent with literature data (Marchionni et al., 2013; Mercurio et al., 2014) allowed a clear differentiation with the Aglianico del Vulture (0,7069-0,7079).

Genetic analysis differentiates Aglianico Taburno clones from Vulture and Taurasi's Aglianico. The polymorphism index of SSRs (Simple Sequence Repeats) molecular markers used in this work is statistically high, capable to identify a rare somatic allele variation in Aglianico Taburno #2 differentiating it from #1 and #3 albeit not to a significant level. The genetic parameters clearly indicate that SSRs markers are strongly suitable as DNA fingerprint tool.

Gene expression atlas was performed evaluating the transcriptome of 9 individuals, sampled from three sites characterized by the totally different soil types described above; the aim of this work was to explore how three different types of soil may influence Aglianico Taburno ripening. Berry skin, flesh and seed RNAs were analyzed to determine differential activated pathways. Although a different ripening degree of the grapes collected (P2

Marchionni S., Braschi E., Tommasini S., Bollati A., Cifelli F., Mulinacci N., Matteri M., Ponticelli S. (2013). High precision 87Sr/86Sr analyses in wines and their use as a geological fingerprint for tracing geographic provenance. Journal of Agricultural and Food Chemistry, 61, 6822-6831.

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Structural setting of the Campanian Plain inferred from Rayleigh wave dispersion

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Keywords: ambient noise cross-correlation, earthquake recordings, fundamental-mode Rayleigh waves.

The Campanian Plain is a graben like structure mainly filled with Miocene–Pleistocene alluvial, terrigenous and marine sediments deposited on Mesozoic carbonate sequences. Such a cover is interbedded with volcanic soils. The Plain, indeed, is bordered by quiescent volcanoes in the North (Roccamonfina) and active volcanoes in the South (Campi Flegrei and Mt. Vesuvius) and has been the site of past volcanic activity as testified by the huge thickness (1.5-2 km) of trachitic lava bodies found in deep drillings of Parete (1.8 km deep) and Villa Literno (3 km deep) up to the bottom.

Shear wave (V_S) velocity models (up to 73 km depth) have been obtained, below the Campanian Plain and the neighbouring areas towards the Mt. Vesuvius and Appenine chain, by the non-linear inversion of group velocity dispersion data of fundamental-mode Rayleigh surface wave, extracted by frequency-time analysis from earthquake recordings and, mostly, from seismic noise cross-correlations between two receivers. In the inversion, local data (up to ~7 s) were joined with regional phase (25-80 s) and group (10-150 s) velocity data (Costanzo & Nunziata, 2014 and references therein).

The structural model of the investigated area, inferred from the obtained V_S models, is characterized by a covering of pyroclastics and alluvial sediments (V_S from 0.5 to 1.7 km/s) up to 1-3 km depth. At ~1-3 km a V_S increment (2.3-2.7 km/s) is found, increasing to 2.8–3.5 km/s at ~4 km depth, possibly related to the carbonate platform. In fact, taking into account the V_P/V_S ratio of 1.8 assumed in the inversion, the corresponding V_P velocities fall in the range 4.0–6.4 km/s measured in the campanian carbonate sequence. However, the presence of lava bodies within the carbonates cannot be excluded in the light of the same density and seismic velocities (Costanzo & Nunziata, 2014 and references therein).

At greater depths, in the central part of the Plain, a sharp increment of V_S (3.85 km/s) is found at ~8–9 km depth, which can be attributed to the presence of metamorphic rocks, overlying a low V_S layer (reduction of 5 %) detected at about 14–15 km depth.

A V_S reduction is also found at 8–9 km (-4 %) depth towards the Apennines and at 6 km (-15 %) depth in the southernmost part of the Campanian Plain, nearby Mt. Vesuvius, within the sedimentary sequence.

The presence of such low velocity layers seems to be a regional feature since it has been found below the whole peri-Tyrrhenian margin, and can be explained with the presence of partial melting and/or to the brittle-ductile transition zone.

The Moho discontinuity, with V_S of 4.2-4.3 km/s, is retrieved at ~ 25 km depth below the Campanian Plain in sensu strictu, and deepens to ~34 km depth, towards the Apennine Chain.

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Tetra-Plot: A Microsoft Excel spreadsheet to perform tetrahedral diagrams

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Keywords: Tetra-plot, mineralogical data, geochemical data, petrological data.

Tetra-plot is a Microsoft Excel spreadsheet developed for the visualization of mineralogical, petrological and geochemical data in three dimensions. This program allows to normalize and plot a number of data on tetrahedral diagrams. The tetrahedron can be freely rotated in space. Tetra-Plot includes a set of functionalities that help users to manipulate data for 3D visualization.

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The Falconiera tuff-cone eruption and its impact on the 132 ka BP Ustica island environment (Southern Tyrrhenian sea, Italy)

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Keywords: Ustica, Falconiera tuff-cone, Cladocora caespitosa, Neotyrrhenian, eruption impact.

The island of Ustica, located 60 km north of the Sicily coast, west of the Aeolian arc, is the top of a vast submerged volcanic complex that rises more than 2,000 m from the bottom of the Southern Tyrrhenian sea. The emerged part of the Ustica volcano covers an area of about 9 km^2 and reaches a maximum elevation of 248 m a.s.l. It is mainly composed of volcanic rocks, and subordinately of marine and continental sedimentary deposits. A Pleistocene age has been assumed for the birth of the Ustica volcanic complex, whereas more recent geochronological studies demonstrated that the exposed volcanic rocks were formed between 750 and 132 ky. These are the product of both subaqueous and subaerial effusive and explosive eruptions, fed by magmas with a Na-alkaline affinity that range in composition from alkali-basalts to alkali-trachyte. Marine sedimentary rocks are clayey sands, organogenic and detrital fossiliferous limestones, and carbonate concretions. They formed during Middle-Upper Pleistocene sea level high-stands, related to glacio-eustatic movements that also generated five orders of marine terraces. Continental sedimentary rocks are detrital aprons, landslides deposits and detrital fans, related with the more recent geomorphological evolution of the island. The present morphology of the island is the result of the prolonged interplay between volcanism, tectonism, eustatism and exhogenous morphodynamic processes. This research focuses on the effects of the last eruption occurred at Ustica, which formed the Falconiera tuff-cone at around 132 ka BP in the north-eastern tip of the island. This eruption was mainly explosive and phreatomagmatic, with the emplacement of a series of pyroclastic-surge beds that determined the formation of an asymmetric tuff cone. This is the most easily recognizable Ustica volcanic edifice, although its north-eastern sector has been partially dismantled by the erosion. A section of the feeding conduit is exposed northward, showing the solidified lavas that fed the latest stages of the eruption. These were characterized by the formation of an intracrateric lava lake and a Strombolian scoria-fallout deposit.

The eruption occurred during the latest stages of the Eutyrrhenian (MIS 5.5), a warm period characterized by a high sea-level stand (+8 m) and the diffusion in the Mediterranean sea of subtropical flora and fauna. This eruption slightly modified the Ustica morphology, but impacted on both marine and terrestrial environments, burying beach deposits rich of mollusk shells (i.e. *Strombus bubonius, Conus testudinarius, Brachidontes puniceus)*, colonies of corals (*Cladocora caespitosa*) and subaerial plants (*Chamaerops humilis*). The discovery of these organisms, in some cases still in their vital position, along with other geological and geomorphological evidence, allowed the reconstruction of the palaeogeography of this sector of the island at the time of the eruption, and the local environmental impact of this event.

The response of benthic foraminifera to hydrothermal vent influence in the Pontine Archipelago, Tyrrhenian Sea (central Mediterranean Basin)

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Keywords: benthic foraminiferal assemblages, vent, CO2 emissions, pockmark, Pontine Archipelago, central Mediterranean.

The recent discovery of a giant complex venting depression in shallow-waters of the Pontine Archipelago (Tyrrhenian Sea, Italy) represents a natural laboratory to study fluid vent (mainly regarding the CO_2 emission) impact on microbenthic communities and to evaluate the effects of ocean acidification. The Western Pontine Archipelago, located about 30 km away from the Italian Peninsula, is composed of three volcanic islands (Ponza, Palmarola and Zannone). The active fluid emissions have been discovered 3 km off the eastern sector of Zannone Island, in a water depth ranging between 105-130 m (outer continental shelf), and affect the Late Quaternary lowstand and highstand deposits. This area appears as a large depression of about 0.5 km^2 (900 m long and 500 m wide) with an elongated shape.

During the research cruise "BOLLE 2014" (June 2014) carried out by the R/V Urania in the Pontine Archipelago, several grab and multi-corer samples were collected. For the micropaleontological analyses, all samples were stained with Rose Bengal to distinguish living and dead assemblages. Qualitative and quantitative analyses were conducted and some parameters such Diversity index (α-Fisher index) and Faunal density were calculated to define the structure of the assemblage and the degree of environmental stress.

This study shows the response of foraminiferal assemblages to CO_2 emissions that are likely to be the main environmental driver on the microfaunal distribution. The microanalyses on dead and living assemblages allow to highlight changes in the structure and composition of the foraminiferal community that suggest variations in fluid emissions linked to different sector of the giant depression. In particular, a possible shift of the vent activity from the northern to the southern sectors of the study area towards the edge of the Zannone insular shelf is supposed. Very peculiar living foraminiferal assemblage consisting of agglutinated species never found or very rare in the Mediterranean Sea occurs (i.e., *Jaculella acuta* and *Spiculosiphon oceana*), while dead assemblage (dominated by calcareous species) testifies the changes on foraminiferal associations under acidification process. The impact of increasing acidifications on foraminiferal assemblages can be summarized in the following points: loss of biodiversity related to increasing vent activity, increasing of agglutinated group with predominant siliceous component in the test structure, limited living distribution inside the sediment, disappearance of porcelaneous taxa and presence of altered carbonate tests.

This study allow us to increase the knowledges about the ecological features of these uncommon species that, for the distinctive environmental context in which they were found, could represent useful environmental proxies both in recent and fossil records.

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Carbonatite-bearing pyroclastic rocks in central Apennines: a preliminary petrographic report

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Keywords: Pyroclastic rocks, intra-Appenninic volcanism, carbonatite, unmixing, glass.

A small occurrence of pyroclastic rocks has been recently found associated to Cretaceous limestones on La Semprevisa Mt. (Lepini Mts., Volsci Range, Central Italy), constituting a NNW-SSE structure located W of the 'Segni-Montelanico-Carpineto Romano Line'. The host sedimentary rocks belong to the Apenninic Carbonate Platform palaeogeographic domain and consist of white and hazel micritic limestones with subordinate dolomitized limestones and calcarenites. The prevailing textures are packstones/grainstones and wackestones with peloids, benthic foraminifers and bioclasts.

Pyroclastics are exposed for about 2.5 m in length and have a maximum observed thickness ranging from ~0.35 to ~0.70 m. These rocks appear unaltered, dark grey in colour, and characterized by leucite and biotite phenocrysts and phenoclasts. The lower and upper contacts with limestones are sharp and locally affected by small indentations and irregularities. No evidence of contact aureole has been observed. In light of our preliminary observations, the collected samples are likely representative of a recent pyroclastic deposit (upper Pleistocene?). A preliminary petrographic study shows a heterogeneous texture, characterized by the presence of entirely glassy shards and hypohyaline to hypocrystalline lithic clasts, poorly cemented in a mixed silicate-carbonate matrix. Preliminary textural and chemical analyses by scanning electron microscope reveal the presence of mildly evolved silicate glass containing Ca-carbonate globules. These features clearly resemble the unmixing textural relationship widely proposed as possible origin for carbonatite magmas. In addition, crystals of dolomite, perovskite, apatite, pyrite and magnetite are present in carbonate globules. Leucite (partially analcimized) is present both as microcrystal in the silicate and carbonate matrix, and as a fresh phenocryst up to ~1 cm in size. The chemical composition of the silicate glass (as normalized to 100 wt%) is SiO_2 45.8 wt%, TiO_2 1.1 wt%, Al_2O_3 19.2 wt%, Fe_2O_3 10.5 wt%, MgO 1.3 wt%, CaO 10.0 wt%, Na_2O 4.0 wt%, K_2O 7.8 wt%, and falls in the foidite field of the TAS (total alkali-silica) diagram, overlapping the Alban Hills leucitite field. Secondary phases distributed within this silicate melt mostly consists of leucite and alumoakermanite. Survey and additional laboratory analyses (e.g. isotopic dating) are currently underway, in order to better constrain the origin of these CO_2-bearing, K-rich pyroclastic rocks, a further evidence of the intra-Apenninic volcanism in Italy.

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Mineralogical, geochemical and isotopic study of carbonate veins, at the Calabria-Lucania boundary (southern Apennines)

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Keywords: C and O stable isotopes, carbonate veins, southern Apennines.

This study focuses on mineralogical, geochemical and isotopic analysis of the carbonate veins (CVs), embedded in cataclastic deposit of serpentinite rocks, from the Fosso Arcangelo site and of the quartz carbonate veins (QCVs) from Pietrapica quarry, at the Calabria-Lucanian boundary (southern Apennines). The paragenesis of the CVs from Fosso Arcangelo, assessed by XRPD and m-Raman spectroscopy, is made of calcite + aragonite with minor amount of dolomite and rhodochrosite. In QCVs from Pietrapica quarry, quartz + dolomite + ankerite + Mg-calcite + talc were instead observed. The bulk of serpentinite rocks mainly consist of serpentine (lizardite, crysotile, antigorite, polygonal serpentine), amphibole minerals (actinolite, tremolite), phyllosilicates (clinochlore, talc), iron oxides (magnetite) with different carbonate phases (Dichicco et al., 2015). Carbon ($\delta^{13}C_{PDB}$) and oxygen ($\delta^{18}O_{SMOW}$) isotopic compositions of calcite in CVs and Mg-calcite in quartz carbonate veins (QCVs) was examined for the first time to constrain the origin of the fluids. For isotope analysis, about 0.1 mg of powder samples was flushed with helium to remove the air and about 50 µl of 100% H_3PO_4 was added to each sample for conversion to carbon dioxide. Analyses were performed using a GB-II peripheral coupled with a Delta V Plus CF-IRMS. The $\delta^{13}C$ values in the CVs range from -0.81‰ to +2.16‰ vs V-PDB, except for a sample having a $\delta^{13}C$ value slightly more negative (around -3.62‰). In the same veins, the $\delta^{18}O$ values are between +14.04‰ and +18.27‰ vs V-SMOW. The QCVs samples show $\delta^{13}C$ values in the range from -1.79‰ to -3.37‰ V-PDB and $\delta^{18}O$ values range from +20.14‰ to +20.60‰ SMOW. The equation proposed by Minissale (2004): $\delta^{13}C_{(CO2)} = 1.2\delta^{13}C_{(Carb)} - 10.5$, was applied to recalculate the pristine $\delta^{13}C$ values of CO_2 from which carbonate minerals are formed. The $\delta^{13}C_{(CO2)}$ values range from -7.9‰ to -11.5‰ for the CVs samples, and are around -14‰ vs V-PDB for QCVs veins. These values seem to indicate a different source of fluids for CVs and QCVs samples.

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Multi-proxy analysis of two gravity cores from the Gulf of Taranto (Italy): recent sedimentary processes and centennial scale climatic variability

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Keywords: Gravity cores, Sedimentology, Stratigraphy, Taranto Gulf.

High-resolution stratigraphic and sedimentological analysis has been carried out on a deep-water core (C3, 103 cm long) collected at a depth of 1080 m in the Taranto Canyon and on a gravity core (C5, 150 cm long), recovered at a depth of 250 m on the continental slope of the eastern sector of Taranto Gulf. The analysis of the samples encloses: laser grain-size, carbonate content, sand fraction sediment composition, SEM, and XRF analysis in continuous along the core. In addition, on the C3 core has been carried out a Computed Tomography Scanner. On the C3 core using the grain size, composition, sedimentary structure and XRF analyses, eight turbidity events, seven incomplete and one complete, have been characterized. From the XRF analysis were taken into account two elements ratio, **Ti**/**Ca** and **Zr**/**Rb**; Zirconium and Titanium contents are high in heavy resistant minerals (De Meijer, 1998) and commonly they enrich the base of some turbidites due to gravitative settling. Meanwhile, the TAC highlighted a vertical distribution of biogenic traces (*sensu* Wetzel, 1984) in each turbidite events. According to this distribution and comparing with turbidite intervals of the Bouma's sequence, the following associations were supposed: Ta and Tb intervals are not affected by bioturbations; Tc interval is usually affected by Zoophycos; Td interval is affected by Helminthopsis, Chondrites, Lopohoctenium, Planolites and Scolicia; and Te interval is affected by bioturbations of Top Layer.The C5 core has allowed to identified a centennial scale climatic variability by using sedimentological and chemical proxies. The elements ratio considered were: Fe/Ti proxy, interpreted to reflect changes in fluvial input; K/Ti proxy in illite changes, which is transported in greater abundance during cold periods; and Ca/Ti, as an indicator of biogenic carbonate *versus* terrestrial input (Richter et al., 2006). The overall trend showed by the obtained curves of ratio-elements have been matched with the Holocene chronological-climatic scheme reconstructed by Caldara and Pennetta (1996), for the Apulia area. In conclusion, sedimentological parameters have allowed to the climate reconstruction for the last 1800 yr of the sedimentary register in the slope of the Gulf of Taranto.

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Using Olivines to unveil the magmatic structure and timescales on Marsili's plumbing system

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Keywords: Marsili volcano, Plumbing system, Timescales, Diffusion.

The volcano Marsili, an elongated ridge located in the centre of the young (2 Ma) Marsili back-arc basin is characterized by a complex morphology resulting from an abundant magma input into its magmatic system laterally constrained (Trua et al., 2014; and references therein). Its geodynamic context allows the presence of both IAB and OIB magmas. Differentiation is quite heterogeneous along the ridge, going from basaltic to andesitic compositions. Previous studies on the Marsili's plumbing system show the existence of a complex magmatic structure.

The present work aims to identify and describe the main reservoirs through which the less differentiated magmas passed through and to estimate timescales of the processes acting on these systems. Olivines provide such information because it is one of the first mineral phases crystallizing in such magmatic contexts. It chemically equilibrates with its environment within short periods at high temperatures and so it may register its path through the crust. Multi-elemental composition profiles from 56 olivines from 8 basalts and 1 basaltic-andesite were obtained with electron microprobe. Samples cover all the extension of Marsili along the summit of the volcanic structure. Composition variability in fosterite values (Fo) is present within and along Marsili, with the norther sector varying between Fo_{90} and Fo_{84} and central and southern sectors varying between Fo_{90} to Fo_{70}. The majority of the analysed crystals show flat compositional profiles along their cores and mantles, meaning these compositions represent the compositions of the reservoirs where these crystals were for a long period before eruption. Rims of crystals from the central and southern segments frequently reveal disequilibrium episodes by showing either normal or reverse zoning. Crystals with compositional steps were also found. Preliminary modelling of diffusion periods seem to reveal contrasting results within and along the ridge, with periods varying from few days to few years. Results seem to be comparable with similar studies of mid-ocean ridges. Marsili's northern sector shows magmatic conditions similar to slow-spreading ridges and the central and southern sectors are closer to fast-spreading ridges (e.g. Costa et al., 2010).

A detailed study of the compositional variability and timescales related to chemical disequilibrium episodes may constrain residence times within the main reservoirs in a magmatic system and thus it might be possible to estimate magma feeding rates within the plumbing system.

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Case studies of natural hazard risks perception along the Italian Peninsula

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Keywords: Natural hazards, risk percepition, case studies.

Risk perception is the judgment that people make about the characteristics and severity of risks. In the last few years risk perception studies focused on providing cognitive elements to communication responsible experts in order to design citizenship informations and appropriate strategies. Several authors used questionnaires as a tool for providing reliable quantitative data, permitting comparison of the results with those of similar surveys to determine natural hazard risk percepitions (seismic, volcanic, landslides, meteorological, etc...).

Italian peninsula is geologically young and, consequently, subjected to both endogenous and exogenous natural phenomena which determine land evolution and natural hazard (landslide, coastal erosion, hydrogeological instability, sinkhole) for population. Risk perception studies in Italy were also carried out based on surveys in order to investigate whether there is a national importance of natural risks, in particular about Somma-Vesuvio and Phlegrean Fields volcanic risks. However, the problem is a lack in risk perception studies on local situations.

For this reason, we investigated on natural risk perceptions in different Italian places where natural hazards occurred even if they are not reported from mass media, because of they were local events. We carried out surveys in different Italian places affected by different types of natural hazards (landslides, coastal erosion, hydrogeological, sinkholes, volcanic, and seismic) and compared results, in order to understand the population perception level, awareness and civil protection exercises preparation.

Our results support that risk communication should be based on citizen knowledges and conscious about natural hazards. In fact, informed citizen could actively participate in decision of urban development planning and accept positively legislation and regulation introduced to avoid natural risks. The study also focused on citizens conscious in natural risks and evidenced that communication on natural risks could not be based only in transferring emergency behaviors to citizens but also in allowing people to improve their knowledges in landscape evolution in order to assume an aware environmental behavior.

Water of Fier Region in Albania: an inventory of contamination and distribution

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Keywords: groundwater, urban hydrogeology, nitrogen pollution.

This paper deals with a basic knowledge of the groundwater status and of supply water quality through the examination of the sources and the distribution of agricultural and urban contamination (basically nitrite, nitrate and ammonium) of river water and of groundwater, in the area of Fier Region in Albania. Basing of limited available data, the most contaminated zones in Fier District are represented by the Gjanica river basin, the Patos – Marinëz area and the valley of Myzeqe. The major sources of contaminant in the Fier city area are related to wastewater leakages in the river waters and seepages in groundwater flowing in the shallow alluvial aquifer of the urban area. Geochemical and bacteriological analyses have been performed in about 30 sampling sites, including surface and groundwater, immediately implemented by GIS technic in a new inventory. The storage and spatial processing of hydrogeological and hydrogeochemical data including nitrate, nitrite and ammonium concentrations, was done with the help of the Visual Foxpro data base code, which was linked to ArcView for the generation of layers representing spatial distribution of various parameters. Nitrogen sources related to urban sewage are affecting both surface waters, with predominance of reduced compounds, and groundwater, where very high values of nitrates have been locally found. The groundwater contamination inventory presented here is the first scientific study and it represents a major step towards a more informed assessment of groundwater pollution by agricultural and urban source of nitrite, nitrate, and ammonium in area of Fier. Preliminary results highlight the importance of geochemical data to performe a more detailed conceptual model of surface/groundwater interaction and at the same time the urgent need of limitation of wastewater discharge into the environmental targets.

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Magma residence times from diffusion chronology on zoned alkali feldspar phenocrysts from the Agnano-Monte Spina Eruption (4.7 ka), Campi Flegrei caldera (Napoli, southern Italy)

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Keywords: Diffusion chronometry, Campi Flegrei caldera, Agnano-Monte Spina eruption, BSE imaging.

The zoning patterns of crystals are a valuable tool to reconstructs processes occurred in a magmatic system prior to eruption. In particular detailed analyses of the mineral zoning and modeling based on chemical diffusion laws allows to determinate the durations of magmatic processes, providing important constraints for volcanic hazard of active volcanoes, such as the Campi Flegrei (Southern Italy) caldera. The Agnano Monte Spina eruption (A-MS; 4.7 ka; VEI = 4; 0.85 km^3 D.R.E), the highest magnitude recent event in this area, produced pyroclastic deposits with variable $^{87}Sr/^{86}Sr$ and trace elements, suggesting magma mixing between two evolved end-members. Alkali feldspar phenocrysts were hand-picked from samples of A-MS pumice under the binocular microscope, and thin sections were prepared for electron microprobe analyses. Based on back-scattered electron (BSE) images were selected phenocrysts displaying a suitable zoning pattern near the crystal margin, likely representing the last mixing event prior to eruption. The zoning patterns have been analysed by using two different approaches: (1) quantitative BaO compositional profiles by point analyses (at a distance of ~10mm) across the crystals and (2) gray-scale swath profiles, from accumulated BSE, taken along a short transect crossing growth discontinuities parallel to the point profiles. In both cases, each profile was interpolated through a non-linear Boltzmann fit curve with Mathematica® software. However, for the second approach also ImageJ® software was used in order to extract a numerical gray-scale value. Our estimates of diffusion times based on a temperature of 930°C are within tens to hundreds years but showed drastic differences between the two types of zonation profiles: (1) zonation gradients based on quantitative point analyses gave residence times from 8 to 1195 years (2) gray-scale swath profiles gave residence times between 1 and 171 yrs. Thus, residence times from the gray-scale modeling are always younger by about an order of magnitude compared to those derived from BaO concentration profiles. The reason for this deviation is that the spatial resolution of quantitative point measurements is too low and thus interpolated profiles are much smoother than the gray-scale profiles. Because of this artifact shorter diffusion times derived from gray-value profiles should be more reliable. The majority of crystals show residence times of < 60 years. However, a few crystals with significantly longer residence (up to 160 years) also occur. Volcanological and geochronological data on the activity in the Agnano-San Vito area predating the Agnano-Monte Spina eruption suggest that the timescales estimated by diffusion chronology are similar to the time intervals observed between eruptions occurred the last 6 kyrs at Campi Flegrei and thus may represent the reactivation time of a magma that was residing in a shallow reservoir after the influx of a new magma batch that triggered the eruption.

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Using reflectance spectroscopy, morphology and constrained PCA for the assessment of within-vineyard soil variability

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Keywords: Viticulture, Soil, Reflectance spectroscopy, morphology, Multivariate analysis.

Soil has long been acknowledged as an important factor affecting grape and wine characteristics, through its influence on heat retention, water content, and nutritional status. Therefore, knowledge on soil spatial variability becomes a relevant element for sustainable grape and wine production.

Variations on soil characteristics may occur within a few hectares of a vineyard, due to small changes in morphology and parent material layers or to the effects of past human management.

The small-scale (within-vineyard) variability may be difficult to measure. In some cases, the vigour of vine reflects the subsurface variability while, in other cases, the changes in soil variability are detected analysing soil samples taken from many evenly spaced boring made throughout the vineyard. However, conventional soil chemical and physical analyses are both time-consuming and expensive, therefore they are not suitable when large numbers of soil samples need to be analysed, as for high resolution field soil mapping. It has therefore become important to develop and use more efficient techniques to measure soils and their properties. In recent years, soil scientists have become interested in measuring the soil properties using visible-Near Infrared (vis-NIR) reflectance spectroscopy. This refers to the measure of spectral reflectance (SR). Since the characteristics of the radiation reflected from a material are a function of the material's properties, observations of soil reflectance can provide information on the properties and state of the soil.

Information on field scale soil variability based on RS could be improved if one or more auxiliary environmental factors affecting soil development and properties, such morphology and parent material, are taken into account. While within field changes of parent material are not easy and/or cheap to achieve, changes on morphology may be easily and accurately mapped based on a high-resolution digital terrain model which can be acquired using instrument carried on Unmanned Aerial Vehicle (UAV). The rule of morphology would be particularly relevant when the vineyard to map is undulating.

Combined analysis SR and morphologic data need suitable multivariate statistical approachs. For the purpose of the present study, which was carried out in a vineyard of the province of Avellino (Southern Italy), we used a method for structural analysis of multivariate data that combines features of regression analysis and principal component analysis (PCA) in a single framework. It is named PCA with external information on both subjects and variables (or simply Constrained PCA). This approach unifies the two methods, capturing advantages of both. It attempts to explain as much as possible of the data by known structures. At the same times it seeks to find unknown structures inside and outside the known structures. A cluster analysis has been then applied to the constrained principal components to group soil with similar spectral behaviour.

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Correlation between shallow benthic and calcareous plankton zones at the Bartonian–Priabonian transition (Varignano section, northern Italy)

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Keywords: Bartonian-Priabonian transition, Calcareous plankton zones, Shallow Benthic Zones, Magnetostratigraphy.

The Bartonian–Priabonian transition has attracted great attention by biostratigraphers in the last decades in searching for a boundary stratotype section. The Alano di Piave section is the present candidate for Global Stratotype Section and Point (GSSP) of the base of the Priabonian. At Alano, resedimented levels including larger foraminifera are very rare and occur exclusively well below any of the biotic and magnetostratigraphic criteria proposed to correlate the base of the Priabonian, namely the base of the crystal tuff layer called Tiziano Bed, the extinction of the genus *Morozovelloides* and the base of magnetochron C17n.1n. The Varignano section (Trento province) crops out in a quarry, now inactive, ca 80 km west of the Alano section and provides a unique opportunity for direct correlation between Shallow Benthic Zones (SBZ) and standard calcareous plankton zones at the Bartonian–Priabonian transition. This section preserves indeed several coarse bioclastic levels rich in larger foraminifera that are quite evenly distributed across the critical interval, and are intercalated with basinal marls, crystal tuff layers and sapropel-like levels. The Varignano section was deposited in a middle-upper bathyal setting of the Lombardian Basin, near the western margin of the Lessini Shelf, the paleogeographic unit source of the larger-foraminiferal-rich turbidites. There is no evidence of subaerial exposure and erosion of the Lessini Shelf shallow-water carbonates during the Bartonian/Priabonian interval, thus supporting the reliability of the larger foraminiferal events. Our record shows that all the primary and secondary calcareous plankton bioevents are recorded at Varignano in the same order and stratigraphic position as in Alano. The Varignano section spans the planktic foraminiferal Zones E10-11 to lower E14, the calcareous nannofossil Zones MNP16Bc to MNP18 and the Chron 18n to 17n.2n. Biomagnetostratigraphic data allow us to correlate a prominent crystal-tuff layer outcropping at Varignano with the Tiziano bed in the Alano section. Our results demonstrate that the Varignano section spans the upper SBZ 17 and the lower SBZ 18, with the zonal boundary marked by the first occurrence of the genus *Pellatispira*. The latter occurs ca 2 m below the extinction of *Morozovelloides*. This is in contrast with the common usage of shallow-water biostratigraphers, who consider the base of the Priabonian corresponding to the base of SBZ 19. Biotic events from shallow-water environments are rarely directly correlated with those from deep-water setting. The results from the Varignano section, supported by the magnetostratigraphic data, give an exceptional chance to verify the current biostratigraphic integrated schemes and allow us to validate the calcareous plankton correlation, whereas correlations with SBZ need to be revised.

New geological insights on "Fiano di Avellino DOCG" *terroir*

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Keywords: Fiano di Avellino DOCG, Lapio, Pomici di Avellino, Terroir.

The geological features of a terroir have always been recognized as active components of the territory that, along with weather and vine variety, celebrate the development of the typicalness (Van Leeuwen & Seguin, 2006). As a matter of fact, the most difficult challenge is the correct conjugation of these variables for each specific terroir. Campania Region hosts prestigious terroirs, the most famous interesting the Irpinia area.

The main goal of this investigation is to find some correlation between the geological context of the cultivation area and the development of both the grapevine and wine quality. The case study accounts for the Lapio (Avellino province) territory hosting the famous DOCG (Denomination of Controlled and Guaranteed Origin, in English) of Fiano di Avellino (Mercurio et al., 2016) on an area of about 2 km2. The Fiano di Avellino grapes, claiming very old origins, became an ampelographical rarity in the seventies of the last century. Actually, Lapio district represents a reliable example of the relationship between wine production and territory development.

The main geolithological features show Neogene siliciclastic deposits in about 2/3 of the studied territory, hereafter shortly described:

- alternations of unsorted brownish sandstones with greyish marly clays and conglomeratic levels (Castelvetere Fm.);
- yellowish massive silty clays with greyish-yellowish arenitic and gypsum-derived siltstones intercalations (Altavilla Fm.);
- coarse grained litho- bio-clastic limestones, usually arranged as regular beds (Flysch Rosso Fm.);
- alternation of brownish silty-sandstone layers and blue-greyish clays thin beds (Castelvetere Fm.);
- coarse grained clast-supported polygenic conglomerate banks with intercalations of sandstones (Baronia Fm.);
- alternations of varicoloured (reddish, greenish, greyish, purplish) marls and clays with thin and very thin fine grained limestone layers (Flysch Rosso Fm.).

Quaternary pyroclastic deposits (ash and pumice fall layers) related to the Neapolitan volcanic district sometimes blanket portions of the investigated area.

Soils developed on sedimentary substrates are mostly formed by calcite, mica, chlorite, illite/smectite, plagioclase and quartz; subordinately by smectite, dolomite and iron oxides. Volcanic soils are mainly constituted by K-feldspar, plagioclase, mica, clinopyroxenes, and leucite; quartz, smectite and iron oxides also occur in minor amounts.

The above described multidisciplinary evaluations in the Lapio area encourage a further deepening of the relationship between geology and wine.

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The x-ray fluorescence (XRF) core scanning instrument at ISMAR-CNR: a innovative tool for sediment geochemical analysis

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Keywords: X-ray fluorescence, XRF core scanner, bulk chemistry, compositional data.

In the framework of the Ritmare project (SP6-WP1-AZ1-structure for non-destructive analysis of samples) ISMAR-CNR has acquired a third generation Avaatech XRF Core Scanner for the acquisition of high-resolution geochemical records from continental/marine cores as well as drilled rock cores and even speleothemes.

The core scanner is based on the x-ray fluorescence (CS-XRF) and is a computerized instrument for continuous scanning of sediment cores that analyzes the chemical composition of the sediments directly on the surface of the cores and it is also able to collects a high-resolution optical image.

The non-destructive measurements through CS-XRF essentially require no preparation compared to conventional chemical analysis on discrete samples. The high scanning resolution of the CS-XRF (from 10 to 0.1 mm) provides continuous information on the elemental composition of the sediment (the elements of the periodic table from Al to U in a concentration range from ppm to 100%) and allows the accurate study of the sedimentary record.

Detailed scans from CS-XRF have already been successfully used for stratigraphic correlations and studies with several targets including sedimentary and paleoclimatic reconstructions at different time scales. The number of scientific publications produced using data from core scanning XRF shows an exponential increase in the last 10 years, especially in studies of Quaternary marine sediments and Lake deposits.

This technologically advanced infrastructure will become a benchmark for the entire scientific community operating in marine research, nevertheless the compositional parameters can aid in routine sedimentological or lithostratigraphic analysis also in continental studies including even investigation of polluted areas.

The results can be used to get indications of sediment transport, element sources and its pathways as well as environmental changes even due to anthropogenic impact.

Here we present examples of experimental scan XRF application from several sedimentological environments showing the peculiar signature of intervals characterized by different lithostratigraphic units, the presence of tephra layers and changes in redox conditions controlled by oceanographic circulation.

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The structure and history of tectonic evolution of Ust-Belaya segment of West-Koryak fold system (NE Russia)

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Keywords: regional tectonics, geodynamics, Far East Russia.

The large part of north-east Russia is a collage of terranes accreted to Eurasia in Mesozoic and Cenozoic (Zonenshain et al., 1990; Sokolov, 1992; Parfenov et al, 1993; Nokleberg et.al., 1998). Research area is located in the northern part of the West Koryak fold belt. Several key areas of the belt were studied during systematic longstanding research (Sokolov et al, 1999, 2001, Bondarenko et al, 1999; Morozov, 2001; Sokolov et al, 2003). Ñonvergent margins were distinguished form carboniferous time (Belyi 1974; 1981; Nekrasov, 1976; Zaborovskaya, 1978; Filatova, 1988; Sokolov, 1992). This region includes complexes of different ages and varied composition that were formed in oceanic and continental paleostructures.

New data and observations were obtained during several field seasons. Various types of rocks analyzed by different methods. Several geological stages are recognised. Their geodynamic regimes have been identified. For some of them have been reconstructed lateral paleostructures.

<u>Late Precambrian - Early Paleozoic stage</u>. Precambrian ultramafic rocks are considered as subcontinental lithospheric mantle underwent interaction with subduction melts based on the mineral compositions (Bazylev et al, 2009; Ledneva et al, 2012.). Their chemical and mineral composition of pyroclastic rocks (560 MA) points to the formation within the active margin. These fragments of an active margin are the most ancient for NE Asian continental margin. A large number of Late Proterozoic and Archean zircon in metasandstones r. Eonayvaam, suggesting erosion of the ancient continent in source.

<u>Middle Devonian - Early Carboniferous stage</u>. Sedimentary rocks of this age were formed in a shallow forearc basin. Pebbles of ultramafic indicate that ophiolites were eroded in the Late Devonian.

<u>Late Paleozoic-Early Mesozoic stage</u>. Rocks preserved in tectonic blocks in the mélange. It indicate metamorphic (Ar-Ar 265.3 ± 2.6 MA) and magmatic events (U-Pb 260 MA, Palandzhyan 2014) in suprasubduction settings. A large number (PZ-AR) xenogenic zircons shows that the arc formed on the ancient basement.

<u>Late Jurassic - Early Cretaceous stage</u>. Complexes formed in various parts of the reconstructed convergent boundary: accretionary prism; on the slopes of the island arc, hanging wall of the accretionary prism and within forearc basin.

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Identification of effective soil hydraulic properties through an electrical-resistivity-tomography monitored infiltration experiment

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Keywords: soil hydraulic properties, infiltration, macropores, bimodal soil hydraulic functions, non-equilibrium.

Optimal agricultural management practices depend on the reliable quantification of water budget in the soil-plant-atmosphere system as commonly implemented in numerical models. Although such tools are user-friendly and easy to set up, their performance highly depends on the proper characterization of the soil hydraulic properties (SHPs). The most popular soil hydraulic functions, based on simple unimodal relations, rely on few parameters and are suitable for the majority of soil profiles. By following the standard protocols, undisturbed soil samples are collected along the soil profile by using small-sized steel cylinders and transported to the laboratory in order to be subjected to the standard-laboratory techniques for determining the above-mentioned soil hydraulic functions (Hopmans et al., 2002). Yet, the hydraulic characterization of heterogeneous, clayey and preferential-flow-sustaining soil profiles might be corrupted if executed with standard methods. In fact: *i*) the sampling method might destroy the crumb-structure and cause soil compaction by altering the original flow regime, *ii*) sampled soil volume might be excessively small and not representative for field-scale water budget numerical modeling and *iii*) simple unimodal relations might compromise the proper description of the real porous-system characterized by two interacting regions, one associated to inter-aggregate pores (macropores or fracture system) and the other one with intra-aggregate pores (micropores or soil matrix system). The aim of our investigation is to propose a solution for the three aforementioned issues by presenting the identification of the effective SHPs through the inverse modeling (IM) approach. An infiltration process, monitored through an electrical resistivity tomography (ERT) device, has been used in HYDRUS-2D in order to calibrate unimodal, bimodal, non-equilibrium dual-porosity or dual-permeability models. The proposed approach: *i*) is non-destructive; *ii*) involves a larger soil volume; *iii*) employs complex soil hydraulic models. Main disadvantage of complex models is that, contrary to unimodal models for a single pore region, they require many more input parameters to characterize both pore systems, thus requiring more computational effort. The experimental soil profile is located in a rainfed vineyard in the Alento River basin (Southern Italy). An undisturbed soil sample was collected in the top layer (about 20 cm depth) in order to retrieve unimodal SHPs by using standard laboratory-methods. The infiltration experiment was exerted by using a 1.06 ´1.06 m wood-box and water content values along the soil profile, as read by the ERT-sensor, were recorded in five images. The numerical model HYDRUS-2D was implemented in $DREAM_{ZS}$ for the IM.

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A Lagrangian Stochastic model as a possible approach in volcanological applications of remote-sensing techniques

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Keywords: Lagrangian Stochastic model, remote-sensing, volcanic monitoring, fumarolic CO_2 flux, Vesuvius.

In volcanic monitoring, since direct sampling is often impractical and hazardous, or of too low temporal resolution, efforts have therefore been made (since the 1970s) to improve volcanological applications of optical remote-sensing techniques (Pedone et al., 2014). They have proved particularly successful in the UV region of the electromagnetic spectrum, where volcanic SO_2 can strongly absorb radiation, enabling estimation of SO_2 fluxes (Oppenheimer, 2010). In recent time Pedone et al. (2014) found a method (based on tomographic concentration maps) to overcome problems in CO_2 emission estimates expecially for hydrothermal areas, in which SO_2 is not present and CO_2 emission calculation, obtained indirectly from the SO_2 flux, is not possible.

Here we propose a Lagrangian Stochastic (LS) model to simulate the transport of CO_2 (and other trace gases) from single or composite sources that could be performed in several volcanic areas, in high-risk state, as Vesuvius (Southern Italy).

Starting from known CO_2 concentrations open-path measurements (ppm), by using a tunable diode laser, and meteorological conditions, LS model provides a technique, mathematically straightforward, for inferring unknown CO_2 emission rates (t/d) from the fumarolic sources. The surface layer model used in the simulation requires that at least four parameters are known: the surface roughness length, which is related to the height of the elements covering the ground; the friction velocity, which is determined by the vertical transport of horizontal momentum near the surface; a measure of atmospheric stability called the Monin-Obukhov length; and the mean horizontal wind direction. LS models have several advantages over their Gaussian and Eulerian counterparts, since they incorporate wind or inhomogeneity of the turbulence field; and, after the previous promising tests carried out at Vulcano (Federico et al., 2016) and "Salinelle" of Paternò (Southern Italy), we are encouraged to validate the mathematical simulations at the fumarolic field of Vesuvius, as part of an innovative tool to be applied in volcanic monitoring, coupled with the pre-existing surveillance techniques.

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Determining the geographic origin of caper in Aeolian Islands by geochemical analysis

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Keywords: fingerprint, geochemistry, trace elements, geo-lithology, traceability.

Caper is one of the most renowned Italian products in the world. For this reason, it is important to develop a scientific method for determining geographic origin to safeguard this product of "Made in Italy". To identify the relationship between geochemistry of soil and chemical composition of caper, a geochemical characterization of caper from Aeolian Islands, was performed. The Aeolian Islands are recognized to be an important place of caper production due to favourable environmental conditions such as Mediterranean climate, the volcanic soil and exposure to wind and sea spray deposition (Barbera & Di Lorenzo 1982). All these features permit to define the geographic context and the territoriality of agricultural products. The sites tested refer to three cultivations area located in Lipari and Salina. The studied areas in the Island of Lipari, Lami and Pianogreca, belong to the Pomiciazzo and Pianoconte Formation respectively (Forni et al., 2013), while the area of Salina Island, Leni, is on colluvial deposits produced by erosion of the Formations Punta Fontanelle, Pianoconte and Serra di Sciarato (Lucchi et al., 2013). Geologic features of the production area, such as soil type, are assumed to be important factors affecting the determination of origin (Bong et al., 2013). We detected the relationship between major and trace elements in soil and their concentration in caper according to geographic origin. Major and trace elements were investigated by x-ray fluorescence (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS). Data were elaborated with multivariate statistics (Principal Component Analysis, PCA). The analyses of soil by XRF and ICP-MS allowed us to geologically characterize each one of the three areas and to determine a chemical composition of major and trace elements in caper. By the geochemical and statistical analyses we discriminated the soils according to geo-lithological characteristics of each area and identified possible geochemical fingerprint of caper in the Islands of Lipari and Salina.

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"...Every contact leaves a trace...", Locard 1920

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Keywords: Footwear impressions, Paleoichnology, Forensics.

The adjective "forensic" placed next to a word indicating any branch of Science means apply scientific methods and techniques to the investigation of crime. Therefore, a variety of forensic specialists exist: anthropologists, biologists, entomologists, geologists and many others. In particular geologists are involved in investigations for everything related to Geosciences. Geosciences in Forensics have a relatively long but not well known history especially if we think to newborn areas of research such as Forensic Paleontology (*sensu* Sacchi & Nicosia, 2013).

The interest is focused on Paleoichnology (branch of Paleontology developed essentially to study fossil footprints) in Forensics because gives well consolidated techniques to detect, recovery and analyze footwear impressions trackways (at least a sequence of three consecutive footprints). According to Locard's Exchange Principle people involved in a crime could leave footwear impressions *en route* to, at, and exiting from the crime scene (Bodziak, 2000). The Principle, summarized in "every contact leaves a trace" and inferred from Edmond Locard's perception that it is impossible for a criminal to act, especially considering the intensity of a crime, without leaving traces of his presence. This concept has to be kept in mind during every crime scene investigation; even more from an ichnological point of view because of footwear impressions evanescence. The right approach to inspect the place where the crime occurred should be with the expectation and awareness that it always could contain traces.

All the previous researches were focused on the analysis of a single footprint (Forensic Podology) and most striking, without a real ichnological approach. The detection of a trackway on a crime scene expects the use of the same tools and analysis methods to those used for fossil trackways. Precisely for this, I want to prove that footwear impressions and trackways, analyzed with paleoichnological methodologies, can give distinctive information such as the locomotion type that is necessarily related to the trackmaker's deambulation. Indeed, the attempt to extrapolate characters from trackways has been done based on the rationale that many characters of human locomotion derive from biomechanical constraints which are strongly related to the physical structure. The results suggest a very high possibility to discriminate the males from the females by their trackways as well a high possibility to recognize the trackways imprinted by the same individual.

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A glance at the geological story of the Ghermi Chay, NW of Iran

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Keywords: Regional metamorphism, Alborz-Azerbaijan, Cordierite schist, Geology of Iran.

The study area is located in the NW of Iran and classified within the Alborz-Azerbaijan Geological Zone (Nabavi, 1976). According to the field investigations and petrographic and geochemical analysis, there are granite, granodiorite, tonalite as igneous, and hornfels, marble and various schist types as metamorphic rock terms in the area (Ryazi Khyabani, 2006). On account of some reasons such as non-metamorphic nature of the Paleozoic formations, the relative age of these rocks has been determined back to Precambrian. There is a granitoid intrusion (the largest intrusive body in the study area), cut by some darker dikes. These secondary dikes that consist of granodiorite and tonalite rocks have probably post-collisional I-type granitoid nature. Furthermore, the area has experienced different metamorphic and deformational phases, which has made it very difficult to find out the true geological history that it has left behind. However, bringing the collected data and acquired information together, the geological scenario of the study area is hypothesized as the following stages: a) The M1 is a contact metamorphic phase and it has formed as the result of the increasing of thermal gradient of calcareous and pelitic rocks by mafic intrusions, that now are recognizable as the amphibolites. The presence of forsterite mineral (tremolite, diopside+forsterite zones) in the calcareous prolotith (Ryazi Khyabani et al., 2006) and the formation of cordierite (chlorite, biotite, cordierite zones) in the pelitic protolith, that have been occurred under the same temperature regime, are related to the M1; b) The M2, as a regional metamorphic phase within the subduction zone, is contemporaneous with D1 deformational phase which has created the S1 foliation. M2 has been probably along with the crystallization of low grade metamorphic minerals; c) The M3 is a regional metamorphic phase that has caused the muscovite growth, the serpentinization of olivines and pyroxenes, recrystallization of plagioclases, and formation of new biotites within the amphibole minerals. D2 deformational phase, which is distinguished by development of the crenulation cleavage, is affiliated to the M3. Through the regional metamorphism, and under a green schist facies, the primitive basic rocks of the area (mafic intrusion of M1) have changed to amphibolites; d) Finally, the last phase in the area has occurred in the result of intrusion of the granitoid mass that has led to the genesis of hornfelses within the thermal aureole. Cordierite-bearing spotted schists are the products of M4, too. In comparison with the other phases, during the M1, the geothermal gradient has been higher, so that none of the other phases could have significant effects on it.

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Upper Mantle Structure of the transition between Alps and Apennines Revealed by Shear Wave Splitting from the CIFALPS Project

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Keywords: Mantle deformation, seismic anisotropy, Western Alps, Apennines.

Northern Apennines, Alps and surrounding regions are often studied separately. The structure of their upper mantle has been studied repeatedly in the past and some studies reported on the seismic anisotropic properties in the litho-asthenosphere. However, a joint interpretation of the Alps-Apennines transition zone is still lacking, mainly at depth. The China-Italy-France Alps seismic survey (CIFALPS, 2012) provided an improved image of the crust and upper mantle beneath the southwestern Alps and the transition to the Apennines. Here we show the SKS shear wave splitting results obtained from the analysis of teleseismic data recorded by 55 temporary seismic stations along the CIFALPS profile and by some other permanent stations. The strain-induced lattice preferred orientation of olivine minerals within the upper mantle, expressed by the analysis, confirms the NW trending fast polarization directions parallel to the strike of the orogen, in good agreement with the results of previous studies all along the Alpine chain. On the contrary, in the Po-Plain, new shear wave splitting measurements show a scattered distribution; the coexistence of both NNE-SSW and E-W directions provides new insights on upper mantle deformation in the complex transition zone between the Alpine and Apenninic subductions. The comparison of this new dataset with recent tomographic studies and geological improvement should compose a more complete picture of the mantle structure and deformation of this puzzling region.

SESSION S39

The future vision of engineering geology: advances and perspectives for tomorrow's environment

CONVENERS AND CHAIRPERSONS

Francesco Peduto (Consiglio Nazionale Geologi)
Francesco Russo (Ordine dei Geologi della Campania)
Silvia Fabbrocino (Università di Napoli Federico II)
Francesco Marchese (Italferr)

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Investigations and Analyses of the Natural Arch of Palinuro

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Keywords: Arch of Palinuro, geomechanical investigation, laser scanner.

The Natural Arch of Palinuro, located on the south-western coast of the Italian peninsula, is a peculiar geological site resulting from the union of two pre-existing marine grottos. The geological structure is characterized by intensely fractured and faulted carbonatic rocks. The arch, which is about 12 m high and 15 m wide, has been affected over the years by repeated rock falls that have pointed out the very high risk level threatening the tourists underpassing the arch or even just standing on the neighbouring beach.

The collapse mechanisms are due to the combination of several factors: the diffused fracturing state of the rock mass, the detrimental effect of marine aerosol and the dynamic action of sea waves. Moreover, the slender morphology of the arch plays induces a peculiar stress-strain state resulting in the reduction of the normal stresses along the discontinuities of the rock mass, with the consequent abatement of the available shear strength.

The stability conditions of the Natural Arch have been investigated by means of site observations and numerical analyses. Geomechanical investigations have been performed by combining traditional methods (geomechanical station) as suggested by ISRM recommendations (International Society for Rock Mechanics, 1978) with an advanced survey technique known as geostructural processing and analyzing made of laser scanner point cloud.

The latter has provided the detailed mapping of structural information (orientation, spacing, persistence) of the entire rock surface.

On the basis of such observations, stability analyses of the rock mass have been performed by both standard stereo graphic methods and finite element analyses. The latter have been implemented by modelling the rock mass as a continuous but anisotropic medium, equivalent to the discontinuous rock mass. The results obtained by the overall process of investigation have provided the necessary information for guiding the design of possible measures that could guarantee arch stability and public protection, keeping also the original beauty of the arch. Such measures consist in the application of external forces by means of special structural elements that will modify the stress state of the rock mass, in order to reduce the gap between maximum and minimum principal stresses.

International Society for Rock Mechanics. 1978. Suggested methods for the quantitative description of discontinuities in rock masses. International Journal of Rock Mechanics and Mining Science, 15, 319-368.

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Brenner Base Tunnel: Excavation through the Periadriatic Line with a cataclastic extension of over 1000 m. Geological and geotechnical conclusions.

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Keywords: periadriatic line, fault zone, exploratory tunnel, convergence, geotechnical monitoring, deformation.

The Brenner Base Tunnel runs at almost a right angle to the Periadriatic Line, the main fault zone in the Alpine range. The project, which stretches almost 64 km between Italy and Austria, is divided into a first construction lot devoted to driving through the Periadriatic Line by blasting, not the fastest excavation method, but more flexible and therefore more appropriate to managing the complex geology of the fault zone.

The excavation through the Periadriatic Line took less than three years, even though it proved to extend further than had been predicted. From the Mules lateral access tunnel moving northwards, the excavation ran first through Brixner granite and then reached the tonalites of the Mules Lamella, which are separated from the granite by a first fault. Since April of 2012, the excavation has intersected the main part of the Line, crossing another 800 m of strongly altered rock in the almost total absence of water. In all, a total of 16 lithotypes were identified, mostly black phyllites, quartz schists and micaschists in varying degrees of cataclasis. Green schists, paragneiss and triassic Austroalpine rocks (metaconglomerates, meta-arenites and dolomites) were also found.

In order to hold up under the significant pressure of the rock, steel ribs, fibre-reinforced shotcrete and self-drilling radial and inclined bolts were used.

The excavation front was consolidated using self-drilling rods, instead of the more usual GRP bars, since they provide the same or greater support and are more easily separate from the spoil, which will thus not be downgraded into waste material, reducing the overall environmental impact. These self-drilling rods made it possible to limit the extrusion of the rock face to 12÷15 cm, which is a considerable, but yet manageable, degree of deformation (within about 2% of the diameter).

Thanks to the excavation of the exploratory tunnel both the geological, geotechnical and hydrogeological model were constantly updated, thus providing data to update predictions, optimize support measures and obtain the geotechnical parameters needed for the subsequent planning of the main tunnels.

The continuous changes in both the quality and the behaviour of the rock mass were managed during the works by using the observational method, that is by acquiring the pertinent data on the rock face and comparing the results of this monitoring to the expected behaviour. Using this method, it was possible to adjust the project with highly satisfactory results in terms of both timing and estimated costs.

The final geological model shows significant stratification, both subvertical and subperpendicular to the axis of the excavation, an anisotropy that matches the data gleaned from the geotechnical monitoring: in spite of the above mentioned deformations of the excavated cavity, the convergence values were between 5÷10 cm.

A comparison of the deformative behaviour of the exploratory tunnel and the two main tunnels showed a fundamental equivalence of the maximum convergence of the various tunnels independently of the diameters.

Mitigation of asbestos hazard in natural environments involved by engineering operations

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Keywords: asbestos hazard, human health.

Asbestos is an important threat to human health, particularly in urban settings where excavation, milling, and transportation of asbestos-bearing rocks during engineering activities (such as quarrying, tunnelling, and railways construction) potentially induce environmental risks for both workers and residents (Gunter et al., 2007).

The difficulty for assessing the in situ occurrence of asbestos depends on the detailed knowledge of the geological properties of the asbestos-bearing rocks, which include the lithology and the tectonic conditions that favoured fibrous mineralisation within the rock volume (Vignaroli et al., 2011).

This work is aimed at discussing the evaluation of the asbestos hazard in ophiolitic rock mass involved by engineering operations, starting from the characterisation of the asbestos-bearing rocks to the classification of particles dispersed in air. By presenting some case histories related to quarrying in ophiolitic rock, we propose a multidisciplinary (geological, petrographical and engineering) and multi-scale (from the scale of the site to the microscale) approach that integrates results deriving from field survey and laboratory.

Our results point out the role of some geological factors in the formation of asbestos. A primary role is recognised in the structural processes favouring the fibrous mineralisation, with correlation existing between the fibrous parameters (such as mineralogical composition, texture, mechanics characteristics) and the particles released in the air (such as shape, size, and amount liberated during rock fragmentation).

We promote some operative indications for procedures to be adopted before starting engineering works involving ophiolitic rocks. Accordingly, we are confident that definition of an analytical protocol based on the geological attributes of the asbestos-bearing rocks may useful for policy makers involved in the mitigation of asbestos hazard in natural environments.

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Characterization of geological and geomechanical uncertainties and risks – The case study of two railway tunnels (Trento, Southern Alps, Italy)

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Keywords: Reference Geological Model, uncertainties quantification, railway tunnels, TBM, cost-benefit rati

The Reference Geological Model (RGM) for underground works projects describes the physical, chemical and geological nature of the territory where the works are planned. In case of railway tunnel, the reliability of the RGM plays a crucial role in the computation of the least possible impact on costs and construction times; calculations and design choices are in fact defined on the basis of the RGM outputs and its uncertainties.

A poorly reliable RGM may cause delays in the construction, or oblige to adopt new design solutions that had not been originally planned; in this unfortunate case, construction costs may increase dramatically, compromising the whole economical sustainability of the project.

In this work we tested a geological risk analysis method related to the uncertainty of the Reference Geological Model. The method was tested on the preliminary design of two railway tunnels near Trento (Southern Alps, Italy).

The two tunnel layouts cross a stratigraphic sequence (Hercynic to Eocene) made of metamorphic basement, Permian volcanites and Triassic-Eocenic carbonate-terrigenous sedimentary rocks. The entire sequence underwent several tectonic phases. Given the geological complexity of the area and the inherent difficulties associated to the interpretation of field data, a realistic uncertainty is introduced in the Reference Geological Model. A new method was therefore developed to quantify this uncertainty.

The method is based on: a) preparation of several alternative Geological Models obtained by modifying the assumed one, still maintaining consistency with the available geological observations and geognostical investigations, b) geomechanical characterization of the materials identified in the models, c) application of a MonteCarlo simulation technique for the prediction of forward times and speeds of the excavation using a Tunnel Boring Machine (TBM).

Comparing the results of the different Geological Models, we obtained a quantitative assessment of the uncertainty of the assumed model and identified the areas where the subsequent investigation campaigns should be planned in order to optimize the cost-benefit ratio.

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Asbestiform minerals and their impact on underground works. A case study of National Railway Project in the Sultanate of Oman

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Keywords: Oman, Railway, Tunnel, Ophiolites, Asbestos.

By the end of the 1980s people began to understand the potential problems, in terms of health damages, related to the dispersion into the environment of some fibrous polymorphous of serpentine and amphibole. Among these minerals, a dangerous and common species is represented by chrysotile, one of the most employed minerals in the field of construction materials since the beginning of 20th century. Furthermore these fibrous minerals can be dangerous when they get excavated during underground tunnel works or rock cutting. The presence of these hazardous minerals in dust produced during construction operations and their spewing into the living and/or working environment has raised considerable concern over the general public opinion that in few instances developed into hostile protests.

The case study, presented in this paper, concerns the geological study conducted within the preliminary design of the National Railway Project in the Sultanate of Oman.

Oman is home to one of the most geologically studied Ophiolite mountain chain, characterized by a peculiar obduction process of oceanic crust. Ophiolites host, in correspondence of their mantle sequence rocks (highly tectonized peridotite and dunite) mineralogical associations rich in serpentine expecially present in veins and fault zones filling.

During two different campaigns many samples were collected and studied through petrographical and mineralogical analysis. Thin sections, analyzed by polarized transmitted light microscopy, allowed to determine petrographic composition of the samples while powder diffractometry (XRD) permitted to acquire their mineralogical characteristics.

The presence of hazardous asbestiform minerals (chrysotile, clinochrysotile and actinolite) was detected in about half of the samples collected. The coupling of these two well-established techniques has secured a fast and reliable reconnaissance of the serpentine polymorphs, which are not readily distinguishable using XRD alone.

Thanks to this analysis it was possible to determine the most dangerous areas in terms of presence of asbestiform minerals and report them, along the geological longitudinal profile of the railway line. The study pointed to characterize, above all, the areas where tunnel boring or rock cuttings were planned.

As a result of this study it was possible to highlight the presence of asbestiform minerals to pay attention to during the excavation process in mantle rock which underwent processes of alteration and serpentinization along veins, fractures or fault zones of the rock mass.

Since this may result in the air-dispersion of natural asbestos fibres, the study also aimed to warn the appointed contractor to evaluate his working methods to eliminate any hazard within the working areas.

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Geological study and field investigation for the definition of a complex structural contact in the design of a railway tunnel (Monte Aglio, Southern Apennines)

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Keywords: geological study, field investigation, geophysical investigation, complex structural contact, rai

During the design of an underground work, the accurate reconstruction of stratigraphical and structural setting is essential for the proper definition of geologic hazard and the choice of construction procedures (i.e excavation methods, coatings, reinforcing elements, etc). This issue is particularly significant in areas characterized by a complex geological and structural setting, as the innermost areas of the Southern Apennines (Di Bucci et al., 1999; Patacca & Scandone, 2007; Bonardi et al., 2009).

For the design of the railway between Naples and Bari the realization of a tunnel to cross the relief of Monte Aglio has been planned. Monte Aglio is located along the drainage divide between the Maddaloni Valley and the Campanian Plain. The tunnel is 5 km long and crosses the lower part of the aforementioned relief with NE-SW direction.

In the studied area, the available studies show the presence of large thrust fault system. It brings the mesozoic carbonate rocks over the pelitic soils of the well know Varicolored Clays (Scarsella, 1971; Carannante et al., 2012). Taking into account the importance of this tectonic element, the design of the planned railway tunnel has required to previously define the geometry of the thrust fault system and associated faults.

The first phase of the study was based on the analysis of existing literature and on large-scale photo-interpretative analysis. This allowed to identify the major tectonic elements in the area. In order to directly observe the structural elements (i.e thrusts and fault), this phase was followed by a detailed geological and structural field survey along the northern side of the Monte Aglio relief.

The all collected data were integrated with the results of extensive boreholes and geophysical investigations. In particular several boreholes were drilled in both the entrance zones of the tunnel, while some deep boreholes in the central zone. These investigations were integrated with superficial geophysical prospectings at the margin of relief and with one deep seismic profile in the central part of Monte Aglio.

The correlation of all the geological studies and boreholes/geophysical investigation made possible to define the geometry of the thrust front and the associated high angle fault displacing the main thrust. Due to the lacking of well exposed outcrops and to the high depth of the thrust faults, the interpretation of the seismic profile carried out along the tunnel layout was very significant for the study. This technique allows to reconstruct with good approximation the geometry of depth tectonic element such as thrust.

However, the geological and structural field survey and the boreholes data are always important. They allow to obtain direct data on the lithological, stratigraphical and structural characteristics of a given area. These data are also essential for the calibration of geophysical investigation and the definition of the geological model.

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The Etroubles tunnel (Aosta): an innovative approach to geomechanical characterization of rocky contests in Alpine geological environment

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Keywords: Geological and geomechanical model, tunneling, site investigations, tunnel planning.

During the works for the construction of Etroubles tunnel, a natural road tunnel of four kilometers as part of an alternative road of approximately 4500 m on National Road n. 27 of “Gran San Bernardo”, in the western Alps, several critical issues have been faced.

They are linked to the high geostructural complexity of crossed rock masses and to inadequate geomechanical and hydrogeological characterization elaborated in the planning stages.

The mountain place and relatively high rock thicknesses involved by the tunnel where was planned the alternative road, were the principal source of the difficulties encountered during the geological investigations. Owing to this, the central geological stretch was almost unknown in terms of geological and hydrogeological conditions and geomechanical characterization.

In a particularly difficult financial period for most of the Italian construction Companies, the several problems found during the construction, in about 3 km of tunnel, brought to the total suspension of work operations and the need of an advanced knowledge of the stretch of 900 m yet to be excavated.

This knowledge had to be raised up to a level such as to minimize the residual technical \ economic risk in the advancement of works process. Owing to the facing of the several critical issues above mentioned, almost the total amount of the financial availability of contract was utilized.

The stretch to be enscavated, placed inside the metamorphic basement, consists of schists traversed by complex fault and thrust systems, within which is present a water circulation sometimes with a significative hydraulic head.

To overcome the various problems in the implementation phase, till to now conventionally faced with constant changes to the project type sections and not foreseen works in occasion of sudden collapses or significant deformation of the pre-covering, was pioneered an innovative characterization method.

This method has been designed specifically on the illustrated context, and founded substantially on the execution of horizontal boreholes surveys, at great depth and specific in situ tests and geophysical analylis.

This methodology, applied for the first time by ANAS and illustrated on May to the President Armani during his visit in the Compartment of the Valle d’Aosta, consists substantially of:

1: sub-horizontal telescopic full coring boreholes, along the tunnel axis, length 200 plus 200 meters, from each side of the work site, with periodical monitoring of direction and tiltness of boring.

2: drilling speed survey, with application of constant drilling parameters.

3.; dilatometric log execution through dilatometric tests every five meters, according to DIB Method (Dilatometric Integrated Borehole), devised by Dott. Valerio Manzon, Geoanalisi Company, under ANAS technical specifications.

4: video inspection, by coaxial optical camera.

5: Geophysical survey of P and S seismic waves along the borehole.

6: measuring the flow rates of the major hydrogeological systems.

7: Collection of samples to be submitted to laboratory tests.

8: data entry in FEM software, to envelope 3D analysis of the detailed Geological Model.

During last winter months, in order to plan and evaluate economically these supplementary investigations, it was performed a field-test on both fronts, with about 40 meters of horizontal destruction drilling and execution of 21 dilatometric tests.

For the operation success, the synergy between the regional Department and ANAS Headquarter in Rome was fundamental. During the field tests, the results were encouraging; the technique has been refined and defined the equipment and most suitable technology to successfully perform the integrative exploration outlined above.

If this new method of investigation should give the expected outcomes, it could become an *ANAS Standard*, with great technical and economic benefits in several cases

More is complex the geological\geomechanical contest, more an extensive knowledge of this, both in planning than in construction phases, to check and eventually optimize the planning choices, can be the right choice for a successful work and a reduction of disputes during in the works.

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Engineering applied geophysics: a 2D and 3D widespread and versatile tool to support risk analysis, planning and construction of strategic railways and civil works

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Keywords: Applied geophysics, geophysical methods, electrical resistivity tomography, seismic refraction to

3D electrical tomography jointed with seismic refraction tomography and/or passive seismic arrays, has recently become a very versatile and widespread tools to apply for the study and characterization of complex geotechnical and geological setup and for supporting, at an early stage and prior the final project, the design of both strategic railways or civil works.

ERT, seismic refraction tomography and passive arrays are well-established techniques for environmental and engineering site investigation (Jones & Jovanovich, 1985; Iyer & Hirahara (Eds), 1993; Bard, 1998; Watanabe et al.,1999; Morelli, et al., 2004; Chambers et al., 2006; Chiara et al., 2011; Harutoonian et al., 2013). On the contrary, the joint use of different methodologies is often not pursued.

This paper aims to show how the combination of different geophysical methods allows to stratify the information coming from different techniques (acting on different physical principles) and, at the same time, how this approach would represent an effective and thorough knowledge tool in engineering geology and civil engineering.

The use of single or joint methods based on electrical resistivity and acoustic impedance properties, selected on case-by-case criteria, applying with surface arrays, are shown, according with different and emblematic case histories.

Moreover, an innovative approach using a combination of surface 3D ERT arrays and surface passive seismic method is illustrated, to overcome the lack of geological or hydrogeological information. This approach is effective, especially in those sites in which the use of direct investigation is not allowed or feasible and/or where it is necessary to act in heavily populated urban areas or when the budget is tight.

The combination and integration of different geophysical methods, allows to define the subsoil model of the investigated areas; those, once integrated with geotechnical results, are able to provide the necessary data for the strategic railway and civil works planning, both in terms of geological setup, useful for the tunnel design in complex areas and for the geological risk assessment.

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Water inflow in tunnelling: knowledge for prevention

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Keywords: tunnelling water inflow safety environmental impact rock mass permeability.

In the last tens of years, there was a strong increase in the execution of deep tunnels for civil infrastructures and hydropower plants; many of these tunnels were executed at depth with a high water head or below rivers or even sea branches. These features and in the event of use of a TBM the need to have all the information largely in advance in order to correctly design the machine, have led to a revival in the studies foreseeing to define the water inflow expected in tunneling and the actions for the protection of the local natural water resources. For the execution of deep tunnels in hard rock mass, it is compulsory to define: a) the 3D geological model with subdivision into homogeneous hydraulic rock masses (HHRM), b) for each HHRM the main parameters associate to the water flow, especially discontinuities network and aperture, and permeability (k). For these purposes, well-addressed preliminary investigations based on field geostructural survey are fundamental in order to define the discontinuities types, setting and networks, according to the necessary working scale. The permeability tensors of the singles HHRM crossed by a tunnel can be obtained starting from the geostructural data through analytic formulas; this procedure also allows to simulate the role played by in situ stress and rock overburden. The knowledge of the HHMR permeability can lead to infer the water inflows in tunneling and the impacts on the water resources of the region and on the tunnel execution. These results must be match to prevention interventions, into a reiterative procedure addressed to define the best excavation procedure suitable to minimize or avoid water inflows and environmental impacts. Failure to do so will result in heavy impacts on environment and works, which could be very costly and at the execution stage of the project.

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Vs models in urban areas from ambient noise cross-correlation

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Keywords: ambient noise cross-correlation, Vs measurements, historical centre of Napoli, historical centre.

The realistic modeling of hazard scenarios needs physical properties of soils which are quite prohibitive to be defined in urban areas.

Aim of this paper is to present an original approach for shear wave velocity (V_S) measurements in urban areas that is based on the non-linear inversion of the group velocities of the fundamental-mode Rayleigh waves extracted with frequency-time analysis from cross-correlation of synchronous ambient noise recordings at two sites. Theoretical research has shown and experimental studies have confirmed that the cross-correlation of noise recordings gives estimates of the Green's function that are dominated by the fundamental-mode surface wave (e.g. Nunziata et al., 2009).

The proposed methodology is low cost as two receivers are requested on ground surface and the depth of penetration is mainly controlled by the distance and the soil velocities.

We show some examples of noise cross-correlation measurements in the urban areas of Napoli (inter-station distances from 0.4-1.5 km) and Gesualdo (AV) (inter-station distances from 0.13-0.8 km), characterized by different geological contexts, that is volcanic and alluvial soils, at Napoli, and sedimentary rocks, at Gesualdo.

As the investigated soil thickness depends on the receiver distance, we present V_S models extending to depths of few hundred of meters.

At the historical centre of Gesualdo, the seismic basement with V_S greater than 800 m/s according to the Italian building code, is found at 40-60 m depth, velocity increases to ~1,400 m/s. Taking into account the geological context, such an increment can be explained with the presence of fractured carbonatic rocks.

At the historical centre of Napoli, Vs from ~500 to ~800 m/s, referable to the presence of Neapolitan Yellow Tuff horizon, from fractured to compact, are generally retrieved at a depth of 10-40 m. Along some paths Vs greater than 800 m/s are reached only at great depths (~70-80 m depth).

The obtained Vs models are relative to depths which are prohibitive by active seismic experiments and allow to define realistically the seismic basement for a realistic estimation of the expected ground motion in microzoning studies.

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Remediation and safe making of the quarry area "Monte Calvario", Mt. Etna

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Keywords: Remediation, fluoro-edenite fibres, geo-structural.

On the lower western slopes of Mt. Etna, the intense exploitation of a volcanic area for the extraction of rock aggregates for the building industry has caused in the last decades a large number of cases of pleural mesothelioma in the inhabitants of the neighboring village of Biancavilla. A rare amphibole - the fluoro-edenite - has been found in this rocks, contained within the fractures of lavas and pyroclastic rocks, as a result of metasomatization processes. Such mineral, asbestos-like, is found in prismatic shape, fibrous and even acicular, with less than one micron of thickness, and in this last size it can be lung carcinogenic if inhaled.

This site was, in 2001, included in the list of the Sites of National Interest (SIN) by the Italian Ministry of the Environment for the remediation of contaminated areas After the closure of the quarry the first safety measures were taken: burial of the loose and dusty materials under clean quarry material (coming from other Etna quarries); paving of dirt roads; coverage with spritz-beton of the outer rocky walls of the quarry. The following phase, after a careful work planning, will be aimed for a permanent safety of the area in order to convert the quarry as an urban park.

In this second phase, a general geological study was followed by the geo-structural survey of very steep or vertical cliffs with the aim of identifying the types of actual or potential instabilities. Identified and defined the size of the unstable rock masses we proceeded to the stability analysis of rock wedges, or through individual sliding surfaces.

For the safety of the quarry slopes have been put forward proposals for their stabilization that took into account the need to avoid excavation and demolition since the fluoro-edenite dust would then disperse after the excavation and could be potentially breathed by the population.

The flat surfaces, already largely covered with clean quarry material, have been characterized through penetration dynamic tests DPSH, with the aim to get the geotechnical data of the foundation soil for the consolidation works.

Finally, we performed a careful hydrological study of the site, in order to proceed with designing and sizing of drainage works and water collection. Rainwater, in fact, cannot be released downstream as they can carry fluoro-edenite fibres. Empirical analysis of rainfall and hydraulic request to completion of the report for the safety of the Monte Calvario Quarry, showed that any intervention with spritz-beton and geomat to prevent erosion and mobilization of material, increase the values of runoff coefficients and then the accumulation of surface water to the closed section of the basin coinciding with the end of the groove. Direct observation of an event with 172 mm in 24 hours did not occur in the expected run-off of the flood plain of Vallone San Filippo which empties into the quarry. The sharp drop of runoff water are deducting caused by strong human settlement involving all the territory and the strem segment, resulting in deviation of the waters, as already mentioned in the PRG of the municipality of Biancavilla.

In this context all the field operations of the quarry had to be made with the same precautions used for activities in areas contaminated with asbestos (overalls, masks, boots, etc.). Both the study phase and the recovery solutions proposed for this particular site will be a reference for other sites contaminated with harmful dusts.

The intervention planned by the project, with the construction of a large glass case that seals one of the fractures with the asbestos-like mineral, also takes into account the importance of this volcanic geo-site, one of the very few in the world where you can find the amphibole fluoro-edenite, often associated with large hematite sheets.

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Definition of the Geological Model for a railway design in a stratigraphically and structurally complex area (Oman, Eastern Arabian Region)

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Keywords: Geological Model, field investigation, geological survey, ophiolite, geologically complex area, Eastern Arabian Region.

The Geological Model is essential for the geotechnical analysis and the design of large engineering works such as railways. The definition of an accurate geological model is strictly related to the quantity/quality of field investigations and it is even more important in geologically complex area.

During the design of the railway in Oman (Eastern Arabian Region), the reconstruction of stratigraphic and structural setting of the studied area constituted a fundamental step, since the entire sector is characterized by a complex geology linked to the presence of one of the largest and best exposed ophiolite complexes in the world (Bechennec et al., 1992; Al-Lazki et al., 2002; Kusky et al., 2005; Forbes et al., 2010; Rollinson et al., 2015).

In order to define the geological characteristics of the area was used a multidisciplinary approach, that allowed a gradual increase of the knowledge by the use of many investigation techniques. Initially was conducted a bibliographic study of the existent literature and then was conducted a large-scale photo-interpretation study that allowed to identify the main geological and geomorphological features of the studied area.

Subsequently was carried out a detailed geological survey, that allowed to integrate the collected data and to develop many geo-thematic maps at 1:25.000 scale. Field surveys had particular relevance for the definition of the geological contact between bedrock and overlying sediments, and for the identification of the major tectonic elements as well (i.e. faults and thrusts).

Finally, the acquired data were integrated by the results of an extensive and detailed field investigation campaign, which included boreholes, geophysical investigations, trial pits, field and laboratory tests. Through all the collected data, and particularly through the boreholes, was possible to define the geological setting along the railway alignment and to reconstruct the geological profile at 1:25.000 scale.

On the basis of the conducted studies and the performed investigations was possible to define a detailed Geological Model of the entire studied area. This model was validated by the GMR-Index (Perello, 2011), which allows to define the reliability of the model according on the geological complexity of the area and the amount of available data. In this way it was possible to define the accuracy of geological reconstruction, in order to have a qualitative estimation of the existing uncertainty in the definition of the model.

The outlined geological model and all the available data allowed to determine the hazard elements and, therefore, to define the natural risks related to the railway design. The reconstruction of geological setting and the definition of the risks allowed to realize a very useful tool for geotechnical analysis and for work design.

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Defence work assessment to prevent beach erosion and river mouth diversion along the Domita Coast (southern Italy) - Experimental survey

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Keywords: Domitia coast, river mouth diversion, beach erosion, defence works.

The northern Campania coastal plain (Domitia Coast, southern Italy) is characterised by the wave-dominated delta system of the Volturno River, with flanking strandplains forming beach-dune ridges partially enclosing lagoonal-marshy areas. The related alluvial plain is a gently sloping alluvial plain crossed by the Volturno River and secondary streams and channels.

The coastal current is directed from NW to SE and is accompanied by a significant solid transport. This involves the mouth diversion of some of the streams; the phenomenon has been recognized and quantized in a GIS environment by a cartographic restoration for the last 250 years.

Currently the volume of mobilized sediments that moves parallel to the shoreline is estimated at ca. 25,000 m3. The amplitude range of the coastal area affected by the current and the solid transport depends on the intensity of storms, with a maximum of about 330 m corresponding to the depth of -6 m.

The present study shows the experimental results of the survey carried out at the "Wave System Basin" of the Laboratory of Hydraulics Maritime (DICDEA), to support technical solutions identified for the protection of the Domitia Coast.

It was suggested the realization of only “cell” made at edges of two semi-submerged groins taking their roots on the ground and connected, on the sea side, to a continuous submerged breakwaters. The cell is divided by some gates.

Taking into account the difficulty of this protection activity, an integration to the enquiries to support the technical solutions found is required, by means of the implementation of experimental tests of a three-dimensional physical model in 1:70 scale (similarity of Froude).

The aim of the experimental survey carried out in the Wave System Basin was to assess the hydraulic behaviour of the construction, its stability, water circulation intensity over the works as well as the beach morphodinamics.

The results obtained prove that the breakwaters have a remarkable defence effect on the beach, since it proves to be sound from a structural point of view.

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Best practice in bioengineering for sustainable development and territory management

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Keywords: bioengineering, territory management.

"The bioengineering is a technical-scientific discipline that studies the methods of use, as construction materials, of living plants and parts of plants, or even of whole plants biocenosis, often in conjunction with non-living materials such as stone, earth, timber, steel" (Schiechtl, 1973). This is the definition of one of the most modern technical disciplines, but at the same time the oldest, dating from the time of the Roman Empire, back to prehistoric times, which bases mitigation and prevention activities of hydro-geological risk on interventions of a low environmental impact, by promoting the protection of biodiversity or the development and sustainable management of the territory. Many are the applications of bioengineering methods in Europe and in Italy, with peaks of excellence in Campania (South Italy) in terms of: design, testing and hydraulic-forestry systems production. The creation of construction works "extraneous" to the nature of the environment in which the works are inserted, is a significant, specific difficulty. There are many fields of application which imply, according to the specific geological characteristics of the area, analysis of phenomena quite complex (slope stability, soil erosion, development of waterways, protection of ecosystems) and environmental impact assessments. Reconstruction of geological and geotechnical model of the intervention, in a high interdisciplinary context, is essential to the effective planning works in terms of choice, sizing and placement. In this study are discussed the so-called "best practices", planning and manufacturing, of hydraulic-forestry systems derived from the large experience in different types of environment (rivers, slopes, wetlands, urban areas, archaeological sites, etc…). In particular, they will be presented and analyzed the design and implementation issues faced in areas with a strong propensity for hydro-geological risks falling within the Campania Region.

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Lessons learned from interdisciplinary efforts towards integrated and reliable procedures for site characterization in seismic areas

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Keywords: seismic and geotechnical characterization, distributed infrastructures, seismic vulnerability.

The formulation of the seismic risk assessment is nowadays based on the sequential analyses of source (M, hypocenter), propagation (for one or few IM) and damages (Pitilakis, 2015). In the last decades significant improvements about the knowledge of the effect of local site conditions on buildings and infrastructures due to the intensity of strong ground motion were achieved, but many uncertainties still affect the existing engineering approaches to the characterization of soil/structure interactions in a framework for seismic vulnerability assessment, especially of distributed infrastructures.

The most critical aspects involve the ground motion variability and spatial correlation attributed to the complex geological features. So the development of a reliable geotechnical model and of consistent methods for the seismic characterization of soils at large scale is a key issue for the territory planning in view of a sustainable lifelines management (Di Carluccio et al., 2009; Evangelista et al., 2011; Fabbrocino et al., 2012, 2014, 2015, 2016).

This study describes the experience of an interdisciplinary research project for a quantitative assessment of real performance of strategic infrastructures located in a wide sector of the Southern Apennine chain (Molise Region, Italy) characterized by structurally complex formations. Some remarks on the regional and local geological, geomorphological and hydrogeological conditions, which control the site seismic vulnerability are given. Finally simplified lithostratigraphical procedures for the implementation of geotechnical models and the evaluation of dynamic parameters is discussed in relation with some real case studies and with field and practice operations in some peculiar sites for the structural safety assessment of historical constructions.

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The management of geological risks in the design of railway infrastructures

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Keywords: Geological model, Geological risks, Geological reliability.

The design of railway infrastructure has the priority of a deep understanding of the geological, hydrogeological and geotechnical settings in order to assess, in the different design phases of the project, the geological risks and constraints.

In fact the geological models are affected by a number of uncertainties that depend on the complexity of the stratigraphic relationships between the different formations, tectonic history, hydrogeological context, availability and reliability of geological existing data, number and quality of geological surveys carried out and, finally, on the critical capacity of the geologist who analyses the above and defines the geological model.

A geological model without any uncertainties does not exist and the underestimation of such uncertainties is one of the main issues during the construction phase, leading to possible litigation and delays of the project schedule.

Therefore, the reliability of the geological model is the necessary goal to be pursued, the greater is the reliability the better is the estimation of uncertainties and risks.

It is necessary to adequately assess the geological risks to predict the actions and methodologies during design phase in order to better manage the infrastructure works during the realization.

This paper will show an example of geological risks management for a preliminary design of a railway infrastructure in Oman.

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Reliability of the geological forecasts in tunnelling: a complex issue with large implications for construction processes and environmental impact

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Keywords: Reference geological model, tunnelling.

Unexpected geological and hydrogeological conditions frequently cause critical situations during the excavation of tunnels or, more generally speaking, of underground works. Uncertainties or, even worst, false certainties, contained in the baseline geological report often imply unforeseen geomechanical conditions and increased environmental impacts as, for example, excessive drainage of groundwater resources, landslides reactivation etc. Unfortunately, like many natural sciences, geology is not an exact discipline and factors contributing to generate unforeseen are multiple and difficult to control, even for skilled experts. In spite of this, the development of a standard concept of "reference geological model reliability" would be useful in order all professionals and entities involved in a tunnelling project are able to get a better evaluation of constructive and environmental risks, and to decide whether further investments in investigations would be needed in order to minimise these risks.

Since the beginning of years 2000 the author, in collaboration with other engineering geology professionals, started developing a standardised method able to provide a rating of the geological model reliability. This method, identified by the acronym GMR, stating for Geological Model Rating, is based on the analysis of the significant parameters that influences the geological forecasts reliability and combine them mathematically via matrix calculations.

The procedure is based on a guided process of score attribution to factors that contribute to build the geological model reliability, i.e. factors regarding the quality of field surveys, direct investigations (boreholes), geophysical investigation. Furthermore also factors defining the complexity of the geological setting and the mechanical heterogeneity of the rock mass are considered.

The result of the method consists of an index varying from 0 to 10, whose dimension is related to clearly defined uncertainties of the reference geological model, e.g.: i) Existence of significant deviations with regard to the reference geological model; ii) Imprecision in the position of lithological or fault zones contacts; iii) Imprecision in the thickness of lithological levels or fault zones; iv) Presence of further critical geological elements of secondary importance besides the forecasted ones (metric to decametric faults/levels with poor geomechanical conditions); v) Presence of further critical geological elements of primary importance besides the forecasted ones (decametric to pluri-decametric faults/levels with poor geomechanical conditions

Some examples of geological investigations for complex tunnelling projects will provide insights on the factors that influence the geological forecasts reliability. Case histories will be shown, among others, from the design and construction phase of relevant AV/AC railway projects like the 64 km long Brenner Base tunnel and the 57 km long Base Tunnel of the Torino-Lione line.

Vibration issues: excavation monitoring during construction of the railway underground link Arcisate-Stabio, function of the geological reference model

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Keywords: Vibration, excavation, monitoring.

The study of vibration and its impact to the buildings, which are placed near the excavation sites of natural tunnels, are related to several factors, i.e. what kind of technology and equipments have been used for excavation. The intensity and speed of vibrations depend on foundation typology, building structure and lithology between excavation and receiver.

Tunnel excavation works for the new railway link Arcisate-Stabio are going on the whole day (24 hours) by demolition hammer. Considering the buildings proximity to the tunnel and the local geology the vibrations has been monitored by using a accelerometer, placed every 10 m along the tunnel front side until the vibration intensity reach high vibration levels with a weighted acceleration (effective average value of the only excavation phase) equal or at least 40 dB; the value achievement performed continuously makes it possible to report timely every criticality to the construction site.

The vibration standards are according to UNI 9614: 1990 "Measurement of vibration closed to buildings and noise evaluation criteria" and UNI 11048:2003 "Mechanical vibrations and impact – Measurement method of vibrations closed to buildings and interference evaluation".

For vibration monitoring was used the "Sinus SoundBook System", fitted out with multi-channel data acquisition system connected to three mono-axial accelerometers. It has been used a high-sensitive accelerometer (1000 mV/g) to enable the measurement in the living environment, where the vibrations are generally low.

The study allows to provide useful information and to describe the vibration impact of excavation according to specific variables: vibration source (hammer), cover thickness, geology, building structure, distance from excavation to receiver. Thanks to the vibration monitoring it is possible to evaluate a propagation model of the vibrational energy. The goal is to calculate through a simplified model the annoyance impact to the population considering the source-receiver distance.

The basics for the aim of the study is the deep knowledge of the geological-lithological model, necessary to obtain fully reliable results about vibrational propagation.

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Proceeding land reclamation the site of railway Terralba in Genova

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Keywords: Terralba Railway Park, soils pollution, groundwater pollution.

In 2007-2008, was found a potential pollution of soils and groundwater at the Terralba Railway Park in Genoa. Pollution of soils concerns Heavy hydrocarbons C> 12, Asbestos and Arsenic, while pollution of groundwater concerns nickel, manganese, aluminum, iron , hexavalent chromium, mercury, total hydrocarbons and polycyclic aromatic hydrocarbons. The potentially polluted site has an area of about 48,000 m². In the site there is a filling coverage, composed predominantly by gravelly-sandy soils and loam soils, for a thickness maximum of 8.20 m. The two lithologies, are interspersed with each other in very different sequences from point to point caused from randomness of human activities deposition. The groundwater is set in the sandy-gravelly permeable intercalations of the filling coverage. The asbestos pollution is only in soils of the filling coverage. It is probably of natural origin and depends from different lithologies used in the past for the leveling of the area. The final version of Risk Analysis has verified the absence of outdoor and indoor health risk and for grondwater,for pollution of hydrocarbons C> 12 and Arsenic in the soils. The absence of risk for grounwater from the polluted soils will have to be guaranteed by the presence of pavings over the source areas identified with Thiessen polygons. The soil contamination by asbestos is not covered by the risk analysis procedures because it is an inert mineral that does not involve health risks if it is not excavated or moved. It is not therefore a risk of the site but a worker safety issue. However, the final version of the project involves the construction on the entire site of a series of interventions that will consist in the construction of two buildings, roads, rails and any little green areas. Therefore, at the end of intervention, all soils currently outcropping the site will be covered by the flooring, from the buildings, from the road surface of the road, from the ballast of the rail and uncontaminated soil in any green areas of furniture, which will eliminate the risk of dispersion of fibers from the ground currently outcropping. For contamination of the groundwater risk analysis found no health risk for volatilization outdoor and indoor. The environmental risk for the receptor groundwater from the same contamination present in the aquifer was not considered because it is unavoidable to respect CSC to the point of compliance and because was more significant arriving at a determination of the CSR to the risk scenarios health for obtaining remediation targets to be referred to for the monitoring of groundwater in progress.In fact, the groundwater monitoring, started in 2009, showed exceedances of CSC in the point of compliance only for Manganese Aluminum Iron and tetrachlorethylene, of which only Manganese persistently. The CdS therefore considered at the time not to prescribe remediation or safety of the groundwater but to continue environmental monitoring of the. Environmental monitoring of the groundwater, which began in 2009, is continuing thus allowing to study the evolution of different polluted in each piezometer in the long run.

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Assessing the degree of risk of the housing stock: the towns of Puglia (southern Italy)

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Keywords: management of the territory, environmental risk, engineering geology.

This paper introduces the possibility to realize a method of analysis of the environmental risk, which supports the planning stage to the management of the territory, in order to mitigate the effects that human activity has on the environment and the consequent danger that pours on humans.

The awareness that there is a risk area "zero" and knowing what may prove costly to its safety, becomes a strategic and effective from the moment of planning to prevent the risk with the best knowledge of the dangers and with the attenuation of the elements vulnerable.

Planning is a time when it can not be underestimated the importance that covers the analysis phase of the territory and municipalities can take action to counter environmental risks primarily in two areas:

• ordinary activities related to land management (such as detailed knowledge of the physical and geological components, urban planning, the relocation work of housing and other buildings from risk areas, compliance with the safeguards laid down by the planning basin and the proper maintenance of the territory);

• the drafting of contingency plans, which must be updated and known by the people, because knows exactly what to do and where to go in case of emergency; in the local organization of civil protection, in order to ensure timely and effective rescue in the event of a disaster.

The risk is the uncertain damage which a person (or object) is exposed as a function of particular events. The risk analysis, therefore, can be made possible first and foremost looking for and defining the type of damage that may occur and, later, by defining the degree of vulnerability, or the degree of exposure to the event which could cause possible damage.

You want to accomplish a territorial database of the area examined by the use of software G.I.S. and to assess what influence have the phenomena of environmental degradation and the danger of natural phenomena, on the town.

It will come to quantify the weight that takes environmental degradation on the effects of the hazard of a site and to define the construction of risk ratings in residential areas. That is, you can go directly to the areas with buildings at higher risk and in need of urgent maintenance work or not.

The application of this method need for a thorough knowledge of the area and the state of the housing stock.

This paper describes the results of fully equipped studies carried out in the towns of Andria, Polignano a and Mare. These centers were considered for morphological differences, lithological, sismic and the housing stock.

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Brenner Base Tunnel: Construction works - intermediate geological and geotechnical conclusions based on the construction of 50 km of tunnels

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Keywords: Brenner Base Tunnel, exploratory tunnel, Periadriatic fault, TBM, NATM, ADECCO.

After excavating a total of 50 km of tunnels in Austria and Italy (access tunnels, exploratory tunnel, main tubes and chambers) driven both by blasting and by TBM, we will show, using examples (TBM in granite, Periadriatic fault, excavation through schists and quartz phyllite), the issues we encountered and the experience we gained in the fields of both geology and geotechnics. The main aspects we have touched on concern:

a comparison of the predicted rock mass conditions with those that were actually encountered;

As it turned out, the types of rock mass had been completely and correctly assessed. The deeper fold structures showed a certain shift as compared to the predicted profile and/or the distribution of the lithological units. The precision in locating subvertical faults was about 20-30% of the overburden. The greatest errors have concerned flat-lying faults, which are difficult to predict and to locate. There are frequent faults parallel to the schistosity. From a hydrogeological point of view, the water inflows into the tunnel were far smaller than predicted. The differences will be shown based on examples (Ampass, Ahrental and Wolf access tunnels, Aica exploratory tunnel and the Periadriatic Line).

- the choice and comparison of the prospection measures for blasting and mechanized excavation;

When excavating by blasting, hammer drillings and horizontal core drilling provide excellent information on rock mass conditions beyond the rock face. In large fault areas, besides core drilling, the installation of magnetic extensometers in hammer drillings are an excellent tool to measure deformation in front of the rock face. The state of the rock mass can thus be assessed up to roughly 3 times the diameter of the tunnel, allowing for the precise adjustment of the lining. The example of the tunnel in Aica shows us that excavating with a TBM and segmental lining requires far greater prospection activities, as large faults can stop the TBM in its tracks. The following additional preliminary prospection measures are needed: continuous preliminary boring, radial boring and seismic tests. Following excavation, besides the recordings and evaluations of the rock face, the analysis of the spoil, tubbing rings with openings to view and assess the condition of the rock, the evaluation of the TBM data, radial boring and the analysis of the entire geotechnical monitoring activities are also required in order to understand the geological model.

- comparisons of geotechnical monitoring and rock mass deformation for differing excavation and lining methods (NATM, ADECCO);

There are significant differences in geotechnical monitoring between Austrian construction sites (using the NATM method) and Italian construction sites (ADECCO method) for the Brenner Base Tunnel. NATM focuses on monitoring the rock mass, mostly by using convergence measurements and single extensometers. On construction sites using the ADECCO method, the prospection programme is far more extensive. Due to the full-face excavation, rock face consolidation is an important part of the method and therefore so is monitoring by measuring the extrusion of the rock face. Also, besides the convergence measurements, the standard repertoire includes installing extensometers on steel ribs and shotcrete and pressure cells. The examples given will illustrate the differences.

The most recent challenge for geologists in the field is excavation with a shielded TBM. The insufficient visibility of the rock mass must be compensated by the interpretation of the data provided by the TBM, the analysis of the spoil, and the interpretation of the data gleaned from indirect prospecting and advanced boring beyond the rock face and around the excavated cavity, with an eye to reducing risk to the greatest possible minimum.

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Innovative remote sensing technologies and new opportunities for the engineering geology research and practice

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Keywords: remote sensing, new technologies, UAV, satellite interferometry, engineering geology.

The recent overview of research published in the international journal of Engineering Geology (Juang et al., 2016) shows that since 1965 the field of engineering geology has expanded from the traditional ground engineering to the multidisciplinary socio-economic domains (e.g., natural hazards, environmental protection and sustainable development). It is in the latter domains that the applied geologists have become increasingly more involved in the recent decades. This implies new challenges as well as new opportunities for the engineering geology community. Further challenges and opportunities result from the scientific advancement and fast development of sophisticated tools and investigation techniques. In this context, here we focus on the innovative techniques of Earth surface sensing, which hold much promise for profitable application in the engineering geology research and practice.

New remote sensing technologies (e.g., LiDAR, UAV) can now provide very high (cm-dcm) spatial resolution imagery for producing detailed topographic maps and DEM. Very high (mm) precision measurements of ground surface and infrastructure deformations can also be obtained (e.g., multi-temporal interferometry techniques like PSInSAR, SBAS). Space-borne radar sensors offer great potential for multi-scale (regional to site-specific) deformation monitoring thanks to wide-area coverage, regular schedule with increasing re-visit frequency, and high resolution and precision of measurement.

The improved (dcm-m) resolutions of the new satellite sensors imply the possibility to derive detailed information that fit the requirements of engineers and is relevant to many engineering geology investigations. Using case study examples we will illustrate how remotely sensed data can assist in the assessment, monitoring and management of:

- natural hazards (e.g., subsidence, landslides, ground deformations in general)
- human-induced hazards (e.g., landfill deformations, subsidence due to ground water and oil/gas withdrawal)
- engineering structures (e.g., stability of transportation infrastructure, dams)
- mining operations (e.g., slope instability issues in open cast mines)

Engineering geologists generally have limited knowledge of sophisticated remote sensing techniques. Hence, focused training and a greater opening of the profession to multi-disciplinary collaborations is needed to fully benefit from the enormous quantities of information the innovative remote sensing can now provide. New collaborations have to be established, e.g., with physicists and electronic engineers specializing in advanced image processing and big data management, and geologists with expertise in the interpretation of digital remotely sensed data.

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ADDENDUM

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Architecture of slope channel systems along the Campanian margin (Tyrrhenian Sea)

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Keywords: geophysical imaging, slope channel systems, Campania margin, Thyrrenian Sea.

Over 30 years of geophysical surveys have shown that, far from simple s transport pathways for large quantities of sediment, submarine channels exhibit a high degree of complexities, expressed in lateral and vertical variability that spans through the entire architectural hierarchy.

High resolution geophysical imaging have been used in this work to enlight the present-day, fine-scale architecture of slope channel systems along the Campanian margin (South-eastern Tyrrhenian sea). The Campanian continental slope is extensively channalized, with a complex drainage network of discontinuous channels that connect successive deeper, largely unfilled intraslope basins bounded by extensional faults.

The character of the slope channels and their range of downslope variations is function of the variations in the margin topography, which is controlled by the tectonic structures. In particular, very low-relief, leveed slope channels in the upper slope fed unchannalized fans as they cross the low-gradient intraslope plains. On the contrary, re-channelization is observed where unconfined flows cross intraslope steps mainly in concomitance with relay ramps. The strong break of slope at the intraslope steps-basin transition can lead to the formation of channel-mouth 'plunge pools' of variable shapes and sizes.

The study of the Campanian margin drainage network reveals a complex, multi-phase history of channel incision/deposition and bypass of sediment gravity flows, resulting in a large variety and alternation of channel-related architectural elements. Slope channels inception, evolution and pathways, as well ad their depositional patterns and internal architecture, are the result of the interaction of the gravity sediment flows with the seafloor, which is in turn mainly dictated by variations of the seafloor gradient.

The resulting unusual arrangement of the geomorphic elements of the Campanian slope channels can be used as analogues for a more complete comprehension of submarine sediment-transfer processes, as well as to discern new insights into channel connectivity and facies heterogeneity.

A contribution to the understanding of depletion phases of springs

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The work presents part of the results so far obtained out of a research about the discharge of springs during no recharge periods (i.e. depletion period or DP). The research is being carried out using numerical modeling on theoretic cases as well as considering the data of a few real springs. It is a common belief that a few days after the end of recharge the DP depends exclusively on the physical characteristics of the reservoir feeding the spring., i.e. on its geometrical properties (shape, extension, thickness of aquifer) hydraulic conductivity and effective porosity. Our findings show that, even for long time periods from the end of recharge, the DP also depends on the distribution of the hydraulic potential at the beginning of the DP or, in other words, on the on the last recharge phases. However, after a variable time (which depends on the intensity and spatial distribution of the recharge and the hydrogeologic and geometric characteristics of the reservoir), the DP apparently tends towards the usual hyperbolic or exponential functions. Our results also show that these equations, from a theoretical point of view, are no more than an approximate description of DP processes of actual springs: even in the case of darcyan homogeneous reservoirs, the depletion coefficients, and related parameters, are not constant. Furthermore, if one considers random measurement errors, it can be shown that analyses carried out on few data sets could give strongly misleading results. These findings help to explain why springs often have different DPs during different no recharge periods and suggest that the estimation of water reserves stored in the spring reservoir have to be taken with great caution.

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S17 - Dynamics of carbonate systems: from facies analysis to global changes

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S22 - Morphodynamic processes at the seabed and in the Plio-Quaternary stratigraphic record of continental margins: georesources and potential geohazards

S23 - Tephras and cryptotephras in Quaternary sciences

S24 - Volcanic and seismic hazard monitoring: from field data to numerical modelling through remote sensing

S25 - Geological safety of built and urban areas

S26 - Remote sensing for the Geosciences and the Environment

S27 - Mapping, monitoring and modeling: tools for landslide hazard assessment

S28 - Geomorphological mapping as a fundamental tool for hazards assessment and risks mitigation

S30 - Groundwater resource among human needs, reuse and environmental requirements

S31 - Traditional and innovative approaches for hydrogeological surveys and monitoring

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S35 - Three centuries of Geology in Italy

S36 - Geoethics: a new way of thinking and practicing geosciences

S37 - Geosciences at school: state of art and perspectives - Le geoscienze a scuola 2016

S38 - Open Poster Session

S39 - The future vision of engineering geology: advances and perspectives for tomorrow's environment

Addendum

Elenco alfabetico degli autori

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