

# SESTA GIORNATA RICERCA GIOVANI



*31 Maggio 2010*

*Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova*

## PROGRAMMA

### SESSIONE 1

#### TUTELA E GESTIONE DELL'AMBIENTE E DEL TERRITORIO

- 10.15 – Eva Azzali: *Characterization of sulfide-rich waste-rock deposits by mean of mineralogy and soil colour*
- 10.30 – Chiara Francesca Schiaffino: *Performance of submerged breakwaters for Levanto and Pietra Ligure beaches protection*
- 10.45 – Ileana Balduzzi: *Morpho-sedimentological and vegetational aspects of the dune field of S'Ena – Sa Chitta and Iscra Ruja coast (NE Sardinia, Italy). Preliminary results*
- 11.00 – Claudia Scopesi: *Pedolandscape studies for the territorial planning of the town of Sassello (SV); some examples and GIS applications*
- 11.15 – Pausa caffè
- 11.45 – Alessandro Sacchini: *Distribution of landsliding in the Upper Scrivia Valley: geological, geomorphological and climatic factors*
- 12.00 – Anna Roccati: *Geomorphological hazard related to heavy rainfalls in the Mt. Penna and Mt. Aiona areas (Aveto Natural Park, Italy)*
- 12.40 – Pausa pranzo

### SESSIONE 2

#### RICOSTRUZIONE DEI PROCESSI GEOLOGICI E GEOMORFOLOGICI ANTICHI E RECENTI

- 14.00 – Francesca Ferraris: *DEM analysis applied to the geomorphological study of nearly-flat surfaces in the Palo area (Ligurian Alps, Italy)*
- 14.15 – Matteo Vacchi: *Geomorphological evidences of past catastrophic events. A way to reduce the current coastal hazard?*
- 14.30 – Matteo Padovano: *Exhumation of Variscan HT-rocks in a restraining bend: the case study of NE Sardinia (Italy)*
- 14.45 – Cristina Malatesta: *A serpentinite channel in the Ligurian Alps? The case study of the Voltri Massif*
- 14.40 – Rita Kraus: *Does the available geophysical and geological data suggest the Northern/Central Apennines to be a “transcurrent belt mountain”?*
- 15.15 – Pausa caffè

SESSIONE 3  
MODELLI FISICI DEI FENOMENI NATURALI

- 15.45 – Donato Belmonte: *Modelling the elastic properties of minerals in the Earth's deep interior: theory vs. experiment*
- 16.00 – Roberto De Ferraris: *Estimation of the local seismic response near the areas affected by the 06 April 2009 earthquake: the case of Paganica, Tempera, Bazzano and San Gregorio (L'Aquila district)*
- 16.15 – Daniele Rizzello: *2-D MASW and refraction seismic in coastal sandy aquifer*
- 16.30 – Massimo Bochiolo: *Radiometric measurements as a tool for geologic and environmental investigations*

## CHARACTERIZATION OF SULFIDE-RICH WASTE-ROCK DEPOSITS BY MEAN OF MINERALOGY AND SOIL COLOUR

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The colour of Fe-rich soils is strongly influenced by the presence of different Fe oxides, oxyhydroxides and oxyhydroxysulfates and by their relative proportions (Scheinost & Schwertmann, 1999 and reference therein). In natural systems, Fe-oxides and -oxyhydroxides are widespread components of soils and other supergenic environments. They also extensively form through oxidation of sulfide-rich deposits (pyrite  $\text{FeS}_2$ , pyrrhotite  $\text{Fe}_{1-x}\text{S}$ , chalcopyrite  $\text{CuFeS}_2$ ). The colour is influenced by original minerals and chemical composition (additional colour-bearing and colourless components), type, particle size, and distribution of colouring minerals, and by the presence of other colouring agents (such as organic matter and oxidized manganese phases; Shum & Lavkulich, 1999). Oxidized Fe phases are strongly pigmenting and, in a waste rock dump with little organic matter, they are more prominent than other pigmenting phases. Because of its tendency to oxidize and precipitate (as oxides and oxyhydroxides) and its inherent strong pigmentation, Fe oxides content may be used as a weathering indicator to study mineralogical and geochemical processes, and to evaluate the accumulation of secondary products (Shum & Lavkulich, 1999).

This study examined the relevance of using the colour of waste rock and tailing samples as a quick indicator of the progress of Acid Mine Drainage (AMD) processes in heterogeneous waste rock dumps. The site chosen is the main waste rock dump of the Libiola mine (Eastern Liguria, Italy). Previous works (Marescotti *et al.*, 2008; Marescotti *et al.*, 2009) showed that the dumped materials are highly heterogeneous in granulometry, lithology, mineralogy and chemistry, either laterally or in vertical section. Other than the host rock of the ore (basalts and serpentinites), the dumped materials contain high amounts of sulfide mineralization fragments (pyrite  $\pm$  chalcopyrite  $\pm$  sphalerite) showing various degree of oxidation, and secondary minerals (goethite and hematite) that occur as cement filling interclast voids and oxidation crusts (hardpan layers) that cap the surface of the dump. Due to the high sulfides content and to the absence of minerals able to neutralize acidity, this waste-rock dump is still characterized by active and persisting AMD processes.

Twenty-four near surface samples were collected defining a rectangular sampling grid that covers the entire core of the dump. The following analytical techniques have been employed: transmitted- and reflected-light optical microscopy, SEM-EDS, XRPD, ICP-AES, XRF. Moreover chemical and mineralogical data have been used to calculate AMD parameters (maximum potential acidity, acid neutralization capacity, and net acid producing potential). The colour of each sample was measured with a UV/VIS/NIR spectrophotometer and the reflectance spectra were then converted into the coordinates of the Munsell and CIE-L\*a\*b\* spaces. Specific components of colour were examined (hue, value, chroma, L\*, a\*, b\*) and then related to particle size, mineralogical species and bulk chemistry. The colour data were finally processed by geostatistical methods.

The colour of all the analyzed samples is always strongly influenced by the presence of the Fe oxides and oxyhydroxides formed as a consequence of the AMD processes, even in the samples where

these minerals are not the main components. Following the Munsell coordinates, all samples resulted consistent with the mineralogical data; the yellow hue is clearly related to the diffuse presence of goethite whereas the red hue to the dominant presence of hematite. Also considering the CIE-L\*a\*b\* system, the colour of all samples is characterized by positive correlation between +a\* (red) and +b\* (yellow) coordinates with the mineralogical composition.

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## **MORPHO-SEDIMENTOLOGICAL AND VEGETATIONAL ASPECTS OF THE DUNE FIELD OF S'ENA – SA CHITTA AND ISCRA RUJA COAST (NE SARDINIA, ITALY). PRELIMINARY RESULTS**

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The aim of this project is the study of the evolution of the dune field of Capo Comino (NU, Italy), between S'Ena - Sa Chitta and Iscra Ruja, by the integration of sedimentological, morphological and vegetational data. This approach has already been used in northern Sardinia (Platamona - SS, Italy) where we obtained very good results to understand the evolution of the dune field and to establish also the quality and naturality of this area (Balduzzi *et al.*, 2006; Vagge *et al.*, 2007).

The target is to fix the elements for a future monitoring and to test the model in a non-anthropized coastline.

Capo Comino beach is developed between S'Ena - Sa Chitta village and Iscra Ruja island. It is 3 kilometres long and characterized by two wide cells broken by metamorphic outcrops.

In a bioclimatic point of view, following Rivas-Martinez classification (1999), this area is classified as Mediterranean Thermomed Terranean Sub-humid (Stazione Cantoniera S.Lucia, NU - Italy).

The main winds that influence the coastal dune field are those with a smaller frequency (as N-E and S-E winds) and they have not any evident trajectory and intensity changes. The third and fourth quadrant winds, coming from S-W and N-W, even if characterized by a stronger intensity, are partially bounded by Mount Albo (as for the N-W wind) and Punta Artora (as for the S-W wind). So they do not influence the structure of the Capo Comino dune field particularly.

The analysis of the Atlas of the Italian Beaches (CNR & MURST, 1999) indicates that the first northern cell is under erosion, in particular in the central sector that is exposed to Tyrrhenian storms; while the second cell is under accretion because submitted to sedimentary deposition during flooding events and to the beach-cast *Posidonia oceanica* material accumulated along the coast also.

The remote sensing interpretation by aerial photographs (1977-2002) confirms the general erosion of the beach, in the northern sector particularly.

We studied the aspects of the vegetation by phytosociological methods (Westhoff & Van deer Maarel, 1978; Rivas-Martinez, 1987; Gèhu, 1988; Gèhu & Rivas-Martinez, 1981) in order to establish the current phytocenosis, their ecology and dynamic and to describe the relative landscape model (Arrigoni, 1996; Biondi, 1999; Biondi *et al.*, 2001, 2004). Vegetational data with the previous morphological and sedimentological analysis are extremely important to highlight the sedimentary environment and the aeolian transport.

To achieve an integration of vegetational, sedimentological and morphological data, series of analysis of several transects along the lines of dominant winds were carried out during the summer 2009. Vegetational data and sedimentological samples were collected along these transects to allow a correct interpretation about coast evolution.

The first results show that, even if the anthropic impact is not so considerable, the dune field had some modifications and a considerable erosive process due to several factors (not least the natural sea ingression during storm events). Erosive processes seem to hit the beach in the central sector subjected to the storms particularly.

The most wide and high dunes are located in the southern sector of the beach where the dune field has its maximum extension and the phytocenosis have good quality and naturality.

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## MODELLING THE ELASTIC PROPERTIES OF MINERALS IN THE EARTH'S DEEP INTERIOR: THEORY VS. EXPERIMENT

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Recent improvements in computing capability and the development of accurate computational codes render feasible the investigation of the Earth's deep interior mineralogy by first principles methods. *Ab initio* all-electron DFT calculations performed within the LCAO (Linear Combination of Atomic Orbitals) approach offer an independent way of assessing the accuracy of the values of various thermo-physical properties (such as elastic constants, bulk modulus, shear modulus, Young's modulus, Poisson's ratio, longitudinal and shear wave velocities, along with their P and T derivatives) and show a very good agreement with experimental data obtained at HP-HT conditions (Ottonello *et al.*, 2009a, 2009b, 2010).

In this contribution, theoretical calculations of the elastic and seismic properties of MgO, one of the most abundant phase in the Earth's lower mantle, are performed up to pressures of 150 GPa and compared with experimental results (Sinogeikin & Bass, 1999, 2000). Single-crystal seismic properties are derived from elastic constants by solving the Christoffel equation for a cubic phase and are found to be highly anisotropic due to many-body interactions. The elastic moduli (bulk modulus, shear modulus, Young's modulus and Poisson's ratio) and seismic velocities (longitudinal and shear wave velocities) of polycrystalline aggregates are then calculated from single-crystal properties adopting a Voigt-Reuss-Hill or Hashin-Shtrikman averaging scheme. Pressure effects on elastic properties are also investigated and discussed, as well as some geophysical implications for the anisotropy of the Earth's lower mantle.

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## RADIOMETRIC MEASUREMENTS AS A TOOL FOR GEOLOGIC AND ENVIRONMENTAL INVESTIGATIONS

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Measurements of  $\gamma$ -ray are frequently used in geophysical surveys to determine the distribution and concentration of uranium, thorium and potassium, the three most abundant natural radioelements in the Earth's crust. This information is of interests to many geological aspects, spanning from general studies on the thermal history of the Earth to practical purposes, such as rock type discriminations, petrogenetic investigations, geochemical prospecting, exploration of mineral resources, environmental radioactivity studies. This paper presents some applications of *in situ* and laboratory  $\gamma$ -ray spectrometry with special reference to the discrimination of lithology and for radiation dose assessments. The study area belongs to the internal and intermediate sectors of the Ligurian-Briançonnais domain (Western Liguria, Italy). First, a radiometric survey was carried out to determine U, Th e K concentrations of the main lithotypes. Finally, the interest is focussed on an abandoned uranium mine to discuss methodological problems of in-situ techniques in radioactivity surveys of underground environments.

The surveyed area is characterized by three groups of rocks: a pre-Namurian polymetamorphic basement (orthogneisses and granitoids), a Permo-Carboniferous metasedimentary (phillytes, quartzschists and micaschists) and metavolcanic (metaandesites, granodiorites, metarhyolithes and porphyric schists) sequence and a meso-cenozoic sedimentary cover (orthoquartzites, arkosic sandstones, conglomerates, dolomites, limestones and calc- and pelitic schists). Surface measurements were performed with a  $\gamma$ -ray apparatus consisting of a NaI(Tl) scintillation detector connected to a 256-channel pulse-height analyser. See Chiozzi *et al.* (1998, 2000) and Verdoya *et al.* (2009), for details about instrument calibration and data processing. On the whole, the spatial distribution of U and Th is strictly related to the geological characteristics. Palaeozoic rocks show the highest contents, while the Meso-Cenozoic sequence is relatively poor in radioelement. Maxima of U, Th and K concentrations are always related to metarhyolithes and porphyric schists, whereas minima are associated with Miocenic bioclastic limestones, which often exhibit negligible U amount. Within metavolcanics, the increase of radioelement content reflects the tendency of U, Th and K to segregate from other rock-forming minerals during magma evolution. Moreover, the fact that Th/U and K/U raise while Th/K decreases with differentiation, provides empirical evidence that metavolcanics belong to a calcalkaline series evolving towards low-K trend products. Among the sedimentary rocks, positive K and Th anomalies are related to continental terrigenous lithotypes and pelitic schists, respectively, the former mainly due to the presence of rhyolitic, feldspar-rich, clastic materials, the latter to the presence of clay minerals. Similarly to the distribution of U, Th and K, the inferred values of  $\gamma$ -ray dose rate generally reflect the lithology. The highest dose, always below a significant hazard threshold, is related to acid metavolcanics while minima are associated with limestones and dolomites.

The presence of a U mine bored in the porphyric schists near the surveyed area allowed us to investigate the applicability of *in situ* spectrometry in underground environments. A set of  $\gamma$ -ray measurements was performed in the laboratory on samples collected along the mine tunnel at points coinciding with those measured with the portable spectrometer. The laboratory spectrometer consists of

NaI(Tl) scintillation detector, housed in a 5 cm thick lead case and connected to a 2048 channel analyser. Laboratory measurements, performed according procedures described by Chiozzi *et al.* (2000, 2002), indicated high U content, anomalous U/Th and U/K ratios and a systematic overestimation of data determined with portable apparatus, with a maximum bias for U. As expected (Mareš, 1984), we observed overestimations of in-situ measurements, probably due to violation of  $2\pi$  geometry condition, resulting from a larger number of  $\gamma$ -rays produced by walls and vault of the tunnel. From the measured radioelement concentrations, we estimated the absorbed dose rate. The potential radon flux and the expected radon concentration in the mine gallery was finally inferred by taking into account the specific exhalation coefficient proposed by Åkerblom & Lindén (1996), the degree of fracturing, the rock uranium content and the type of minerals. These quantities are at least one order of magnitude greater than those observed at the surface and are relevant to radioprotection rules.

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**ESTIMATION OF THE LOCAL SEISMIC RESPONSE NEAR THE AREAS  
AFFECTED BY THE 06 APRIL 2009 EARTHQUAKE: THE CASE OF  
PAGANICA, TEMPERA, BAZZANO AND SAN GREGORIO  
(L'AQUILA DISTRICT)**

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In the field of the activities planned by the Dipartimento della Protezione Civile, following the earthquake of April 6<sup>th</sup>, 2009 that affects the city of L'Aquila and its district with the aim of individualizing suitable areas to the reconstruction, the Dip.Te.Ris. of University of Genoa has effected a seismic monitoring finalized to the characterization of the local seismic response of some sites near the city of L'Aquila. The investigated area includes the villages of Paganica, Tempera, Bazzano (industrial area) and San Gregorio that were high damaged by the seismic sequence. In the inclusive periods between the 20<sup>th</sup> and the 29<sup>th</sup> of April, between the 6<sup>th</sup> and the 24<sup>th</sup> of June and between the 24<sup>th</sup> of June and the 2<sup>nd</sup> of July, three different temporary seismic network, that have allowed the definition of the of local seismic amplification effects of 31 sites, have been installed. For every site, the amplification function (frequency

of resonance and level of amplification) has been determined through the analysis of over 800 earthquake records, including magnitude between 1.5 and 4.5, recorded in correspondence of different geological situations.

Traditional methodologies, based on the calculation of the ghostly relationships, have been applied considering both single station method (Nogoshi & Igarashi, 1970; Bindi *et al.*, 2000) and reference station method (Borcherdt, 1970), based on the installation of a station on outcropping bedrock site. Particularly for every investigated village/municipalities has been selected an opportune reference station compatible with the geometry of every temporary seismic network installed in the various periods.

The results underline the presence of remarkable amplification effects with resonance frequencies that vary between 1.0 and 4.0 Hz, especially in the zone of Tempera and Paganica North-east. The amplification factors calculated on the “weak-motion” data (De Ferrari *et al.*, 2008) show values that oscillate between 1.5 and 3.5. Finally a meaningful effect of amplification of the vertical component must be observed near many analyzed sites, as underlined by the V/Vref curves, that absolutely have to be valued in the application and interpretation of the results obtained through single station spectral ratios technique (H/V curves), that would not be able to guarantee a complete and reliable estimate of site effects.

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## **DEM ANALYSIS APPLIED TO THE GEOMORPHOLOGICAL STUDY OF NEARLY-FLAT SURFACES IN THE PALO AREA (LIGURIAN ALPS, ITALY)**

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A paleo-surface is an erosional surface decoupled by the current erosional activity. It reflects different relief and climate conditions than those operating in the modern, resulting in a “transient” condition as river re-adjust the landscape to reflect these conditions (Whipple *et al.*, 1999). Paleo-surfaces are flat or nearly flat areas characterized by a low local relief, which derives by a long period of stability of the local base level at the moment of their formation. Because of their marginal position with respect to the modern drainage systems, paleo-surfaces tend to be apart from the intense, modern erosional processes, and, in particular, from fluvial incision.

Aims of this work are the classification and characterization of several nearly-flat surfaces located along the Po-Ligurian divide and the Po flank of the Ligurian Alps.

An investigation about the origin and the evolution of these low-slope areas was carried out throughout field surveys and the analysis of high resolution Digital Elevation Models.

Erosional surfaces, and relict surfaces in particular, are key examples of the interaction between tectonics and erosional processes, both for their origin and preservation (Bartolini & Peccerillo, 2002).

The Italian peninsula is rich in summit and ridge surfaces. Both the Alpine and Apennine chains underwent in fact several phases of uplift, even if locally at very different rates, following phases of relative stability (Bartolini, 2004).

The study area is located in the eastern sector of the Savona province (Liguria), within the Beigua Geopark. It covers about 60 km<sup>2</sup> and is characterized by several low-gradient crest zones, among which one of the largest humid areas of Ligurian Alps.

The studied sector goes from the regional divide, between the ‘Monte Beigua’ and ‘Monte Rama’ peaks, to the country of Palo, including the highest part of the drainage basin of the Orba river.

From an high resolution DEM of the area (cell size 5×5 m) a slopes gradient map has been extracted, from which the nearly flat areas (gradient up to 5°) have been isolated and mapped.

This preliminary investigation led to the identification of more than 200 low gradient areas surrounded by escarpments or abrupt changes in the slope gradient. Flat surfaces, mainly located along the crests, have been subsequently elaborated to obtain data about aspect, area, perimeter and mean elevation.

Despite the limited extension of the area studied so far, some preliminary observations can be done.

At least 50 zones, with variable areas, have been confirmed to be ‘isolated’ from the surrounding landscape. These zones can be grouped in two bands of flat surfaces with very similar aspect and elevation.

The first band, which includes the largest paleo-surface of the region, goes from 800 m to 950 m a.s.l. It is mainly composed by fragments of surfaces located along the ridges, surrounded by a deeply incised drainage network.

The second band runs along the regional divide, between 1100 m and 1300 m a.s.l. Streams are here lightly incised and the entire area may be considered a paleo-surface as a whole, considering the great numbers of flat surfaces and the general low relief of the entire divide band.

The existence of paleo-surfaces of variable extensions, characterized by similar deposits, scattered along the Po flank of the chain in a range of elevation going from 800 m to 1300 m a.s.l., allows to hypothesize the existence of a unique paleo-surface, whose origin is still uncertain, subsequently incised and split by erosion and tectonics.

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**DOES THE AVAILABLE GEOPHYSICAL AND GEOLOGICAL DATA  
SUGGEST THE NORTHERN/CENTRAL APENNINES TO BE A  
“TRANSCURRENT BELT MOUNTAIN”?**

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An alternative model for the evolution of the Northern-Central Apennine from Late Miocene to present was elaborated by combining the existing geological and geophysical data (geological structures, seismicity, tomography, geothermal- and GPS-data). This new hypothetical model reinforces the importance of the strike-slip kinematics in the neogenic evolution of the Northern Central Apennines and leads to the conclusion to describe the chain as a restraining bend mountain. The complex pattern of coeval strike-slip and normal shear zones has already been observed, at a smaller scale, in the L’Aquila area (Kraus *et al.*, 2009). In the model suggested by Elter *et al.* (2009) the pattern of “snake” shear zones enhances the formation of pull-apart and coeval pop-up structures. In the present study the applicability of the model to a larger scale for the whole Apenninic chain is discussed.

In the North-Central Apennines the distribution of coeval NE-SW and NW-SE trending fault lines is widespread. Depending on the bibliography they are called “Tettonica Trasversale” (Elter, 1960; Bortolotti, 1966; Castellarin *et al.*, 1978; Fazzini & Gelmini, 1982) or persistent structural barriers (Pizzi & Galadini, 2009). They are mainly strike-slip faults with an occasionally transpressive or transtensive component. Apart from the coeval NE-SW (“Tettonica Trasversale”) and NW-SE line system additionally many pull-apart basins (formerly “intramontane basins”) have formed in the North-Central Apennines. They are generally related to NW-SE sinistral strike-slip faults and NW-SE normal faults. As well as fault lines and pull-apart basins the occurrence of pop-up structures also belongs to the list of structural features in the Apenninic Chain. Additionally the Northern and Central Apennines are characterized by the occurrence of an instrumental seismicity of moderate to intermediate magnitudes up to 6.0, which events are generally concentrated in the first 20 km of depth (Frepoli & Amato, 1997). In general the focal mechanisms of the principal events show a great complexity with a high amount of strike-slip and transpressional solutions. The Eastern Central Sector (hereinafter ECS), which is separated from the surrounding sectors by regional strike-slip and oblique shear zones, is – according to the new model – the consequence of the interaction between the coeval forces acting in the Mediterranean area: the subduction of the Ionian Plate, the opening of the Southern Tyrrhenian Sea and the opposition of the Alpine Chain. The heightened seismological activity occurring in the ECS is probably due to its escapement *versus* NE, which also triggered the earthquake from the 9<sup>th</sup> of April, 2009 in L’Aquila. This interaction is accompanied by seismological activity, following or outlining the geologic structures already mentioned above. This happens in particular in the Northwestern Apennines, where the “persistent structural barriers” perfectly mimic the seismicity – or vice versa. In the Northern sector a line northern of the Taro river acts as the limit of the consistent seismicity of the chain, while the southern limit is a zone parallel to the Livorno-Sillaro-Line (hereinafter LSL), which is acting as a transfer zone close to the high heat flux area of Lardarello (Eva *et al.*, 2005). Computing the orientation of principle stress axes by using the focal solutions, a  $\sigma^3$  stress axis oriented NE-SW/ENE-WSW is revealed. In the North-Western Sector (hereinafter NWS), prevails a strike-slip regime, computed on the basis of the orientation of  $\sigma^1$  and  $\sigma^2$

axes (Frepoli & Amato, 2000), which gets also confirmed by borehole breakout analysis (Montone *et al.*, 1995). Thus the seismological evidences confirm a NE-SW extension in agreement with the model proposed in this study for the North-Central Apennines. The complexity of the stress regime in this part of the Apennine Chain lies in its different behaviour with depth. In fact, the orientation of the principal stress axes turns from transtensive at a depth 0-10 km to transpressive below 10 down to 30 km of depth (Eva *et al.*, 2005).

The interpretation of both geological and seismological aspects leads to emphasize the fundamental role played by the system of shear zones and allows us to propose the Apennines Belt (North and Central sectors) as a Transcurrent Belt (Padovano *et al.*, 2009; Elter *et al.*, 2009). These kinds of belts are characterized by “bowed” morphology, coeval presence of restraining and releasing bends, a relevant seismicity and the lack of a typical High Pressure and/or High Temperature overprinting.

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## A SERPENTINITE CHANNEL IN THE LIGURIAN ALPS? THE CASE STUDY OF THE VOLTRI MASSIF

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The meta-ophiolitic units at the eastern border of the Ligurian Alps are characterized by different tectono-metamorphic evolutions. In the Voltri Massif, the Voltri and Palmaro-Caffarella Units underwent high-pressure metamorphic peak conditions, ranging from the eclogitic to the blueschist facies.

In both units, highly sheared serpentinite and metasediments host plurimetric to pluridecamic lenses of metagabbro and metabasites. Poorly serpentinized domains, retaining pristine mantle features, are also largely preserved inside the serpentinite and the contact between the two is often gradual.

In order to define the metamorphic histories of selected bodies inside the Voltri Massif, I studied some metagabbro lenses hosted by serpentinites or metasediments of the Voltri and the Palmaro-Caffarella Unit.

The fieldwork study of metagabbro bodies from the Voltri Unit highlighted that the deformation was active generally during the eclogitic metamorphic stage and during the retrogressive blueschist and greenschist conditions. In the Palmaro-Caffarella Unit both the blueschist metamorphic peak and the later retrogressive greenschist facies assemblages are syn-kinematic. Moreover a marked strain-partitioning is visible both between the metagabbro lenses and the host-rock (serpentinite or metasediment) and between the core of the lenses, where the magmatic textures are preserved, and their rims.

Besides the conventional petrographic analysis, we computed P-T pseudosections for rock samples of different bulk composition using the programs collection PERPLE\_X (Connolly *et al.*, 1990). Pseudosections allowed to define, for every bulk-rock composition and as function of pressure and temperature, the stable paragenesis that corresponds to the minimum of the Gibbs free energy of the system. Comparing the computed and the observed rock assemblages, I traced several P-T paths representing the rock evolutions. According to pseudosections, Palmaro-Caffarella samples reached maximum conditions of  $10 < P \text{ (kbar)} < 15$  and  $450 < T \text{ (}^\circ\text{C)} < 500$ . The samples from the Voltri Unit were characterized by lawsonite stability in the peak assemblage and reached metamorphic peak conditions varying from about 21 kbar and 450-490°C to 22-28 kbar and 460-500°C. In all the studied samples the exhumation path is almost isothermal.

The evidences above (*i.e.* presence of localized deformation focused in the host-rocks and in the outer rims of the lenses, different metamorphic peak conditions recorded by the studied lenses) suggest that the Voltri Massif could have been exhumed through a “serpentinite channel” that dragged from different depths, till crustal levels, kilometric slices of the subducted slab.

Such hypothesis appears to be supported also by the results of 2D numerical modeling: these models simulate an intraoceanic subduction starting within a Ligurian-Piemontese ocean-like basin consisting in a non-layered oceanic lithosphere with discontinuous gabbroic bodies, and a discontinuous cover of basalts. The models are based on a set of equations, solved using the finite differences method, describing the behaviour of viscous, incompressible, heat-conducting media in the gravitational field (Gerya *et al.*, 2002).

The simulations show the formation of a viscous serpentinite channel between the subducting slab and the overriding plate, where a forced return flow of downgoing slab materials acts. P-T paths of metagabbro lenses achieved from the models reach metamorphic peak conditions with gaps comparable with those of the studied rock samples. The numerical models provide useful constraints on the rise of tectonic units exhumed in the channel. A first check of this features enabled to recognize that the size of exhumed units in the model grossly fits the size of the different tectono-metamorphic sectors mapped. Furthermore such models show that only few sediments undergo subduction dragged by the oceanic downgoing lithosphere; the majority of subducted sediments is instead pushed and dragged by the incoming continental crust.

As for other ophiolitic massifs (e.g. the Monviso Massif in the Western Alps; Guillot *et al.*, 2004), the serpentinite subduction channel could be therefore considered a reliable exhumation mechanism for the Voltri Massif where km-scale tectonic slices were exhumed from different depths.

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## **EXHUMATION OF VARISCAN HT-ROCKS IN A RESTRAINING BEND: THE CASE STUDY OF NE SARDINIA (ITALY)**

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The Variscan High Grade Metamorphic Complex belongs to the Sardinian Variscan belt, which can be subdivided in NW-SE trending tectono-metamorphic zones, from south to north: External Zone (Foreland); Nappe Zone; Posada Valley Zone and Axial Zone or High Grade Metamorphic Complex (HGMC, Corsi & Elter, 2006). The metamorphic grade increases towards the NE with the Barrovian-type regional metamorphism isograd parallel to the NW-SE axis of the belt (Franceschelli *et al.*, 2005).

The HGMC consists mainly of a gneiss complex (Elter & Padovano, 2009) characterized by ortho/paragneisses and subordinate types of migmatitic gneisses (diatexites < 5% and metatexites < 10%, Cruciani *et al.*, 2008), with calc-silicate and quartzitic nodules. Bodies of peraluminous granitoids of mainly Ordovician crustal origin (protholith ages close to 465 Ma, Giacomini *et al.*, 2006) and metabasites are also present together with scattered eclogite facies boudin-relics (protholith U-Pb zircon ages 453±14, 457±2 and 460±4 Ma, Cortesogno *et al.*, 2004, Franceschelli *et al.*, 1998, Palmeri *et al.*, 2004, Giacomini *et al.*, 2006), within the Ordovician orthogneiss. Rare occurrences of wollastonite + diopside + decimetric garnet bearing marble (Elter & Palmeri, 1992), amphibole-bearing and coeval

kyanite-bearing gneisses (Cruciani *et al.*, 2008) are also recognizable. The gneiss complex is affected by a later retrograde mylonitic shear event, with syn-tectonic intrusions of granites (320 Ma, Ar/Ar on muscovite and biotite). The mylonitic event gives rise to biotitic gneisses, namely “cat’s eyed facies” (Elter & Padovano, 2009), with centimetric quartz/feldspar porphyroclasts. Widespread late and post-tectonic intrusive magmatism affected the HGMC in a time span from 300 to 280 Ma (Elter *et al.*, 1999; Corsi & Elter, 2006).

Field evidences and finite strain analyses, carried out on the gneissic rocks previously described, show that their emplacement occurred in a transpressive regime which is related with the collision between Gondwana and Laurussia plates, during the Late Carboniferous.

The exhumation of HT rocks in a compressional frame has been partially tested by analogue models, deformed into a thermomechanical apparatus. The models were made out of three layers of plasticine and sand with different physical properties, which should represent levels of the crust with different rheological behaviour. The plasticine used for these models shows a non-linear viscous behaviour (Zulauf & Zulauf, 2004, and references therein), meaning that the viscosity changes in function of the strain rate and the temperature. The results obtained show that the lower crust can be exhumed to shallower levels, assuming thus dome-type geometries.

The evidences provided by the structural constraints and by the analogue models emphasize that the exhumation process of HT-metamorphic rocks could be driven by a restraining bend (pop-up structure) which develops along the eastern transcurrent Gondwana boundary (EVSZ, Corsini & Rolland, 2009). The Variscan High Grade Metamorphic Complex of Sardinia can be correlated with other crystalline massifs (Bohemian Massif, External Crystalline Massifs of the western Alps and Maures-Tanneron Massif), which record a different geodynamic evolution with respect to the one experienced by the French Massif Central and Vosges Massif, connected to a frontal collision environment (Elter & Padovano, 2009).

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## 2-D MASW AND REFRACTION SEISMIC IN COASTAL SANDY ACQUIFER

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Surface waves - based seismic methods (SWM) have known an increasing employment in research and professional fields in the last years (Socco & Strobbia, 2004). This is due to the advantages they offer in seismic and geotechnical site modeling. These advantages are essentially the low cost and the capability to investigate geological environments unfavourable to other geophysical methods, such stiffness inversions and hidden layers (Park *et al.*, 1999).

Among the SWM, the MASW technique has been largely employed and implemented, both from a methodological and theoretical point of view. Usually, the result of a MASW survey is a 1-D shear velocity profile, located at the centre of the geophone array. This solution is an inherent consequence of the inversion process of the dispersion curve, and represent a limit if a lateral distribution imaging of Vs is required (Xia *et al.*, 1999). Nevertheless, by means of an adequate number of acquisition channels, or by roll-along surveying, is possible to make 2-D Vs profiles, by interpolation of several monodimensional profiles, obtained from the analysis of different trace subsets (Grandjean & Bitri, 2004).

The present work is a part of a larger geophysical campaign, carried out to characterize a coastal sandy aquifer in Genoa, Italy. Seismic survey has developed by three 48-channels MASW and refraction profiles, to constrain the MASW dispersion curves interpretation. To obtain the 2-D image of Vs distribution, different subsets of twelve traces have been analyzed, then the 1-D profile have been linearly interpolated. Furthermore, combining the 2D-Vs profiles and the Vp tomographies (Bachrach *et al.*, 2003; Ivanov *et al.*, 2000), it has been possible to calculate the Poisson modulus by the Vp/Vs ratio and to produce its imaging.

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**GEOMORPHOLOGICAL HAZARD RELATED TO HEAVY RAINFALLS  
IN THE MT. PENNA AND MT. AIONA AREAS  
(AVETO NATURAL PARK, ITALY)**

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Climatic conditions occur frequently as the most important dynamical agents for predisposition and activation of hydrogeological instability; they are closely related to other factors such as the geotechnical and geomechanical features of geomaterials, the slopes morphology and aspect, the human activity. Current climate changes and weather variability – which intensifies geomorphological processes and frequency of extreme events – contribute to determine new natural hazard situations and make current critical state worse.

This work presents the case-study of the southeastern sector of the Upper Aveto Valley and, in particular, of the slope located between the Mt. Penna - Mt. degli Abeti ridge and the Gramizza stream (Ligurian-Emilian Apennine).

The orographic configuration of the Upper Aveto Valley – which develops close to the Tyrrhenian-Po watershed with predominant exposure towards N-NE – influences the winds and streams direction and the rainfall supply due to perturbations: when the humid air from the sea meets the colder and drier air from the north, abundant precipitations occur, partly intense. They are often related to geomorphological instability.

Even if the Upper Aveto Valley is not far from the sea, the geographical and physical conditions of this Apennine sector are more similar to an Alpine environment rather than to a typical coastal hinterland. The complex geological setting (Casnedi *et al.*, 1993), the geomorphological processes (Faccini *et al.*, 2009) and the climatic-environmental features involve several natural hazards, due to both geomorphological dynamics and peculiar climatic conditions.

The used methodology provided a preliminary thermo-pluviometrical data collection (Roccati *et al.*, 2009). These data were recorded by various weather stations of the Upper Aveto Valley and the adjacent areas. The obtained data concerned the thermometrical and pluviometrical daily observations over the period between 1965 and 2005: the annual and monthly mean rainfall and temperature have been calculated.

Mock stations have been introduced – located on the basis of the morphological and climatological characteristics of the area – in order to compensate for the uneven distribution of the measurement points and gaps of some series of data; the corresponding annual mean temperature and rainfall height have been obtained by means of the corresponding laws T/h and P/h according to the altitude.

Annual mean rainfall varies from 1350 mm/year at Boschi d'Aveto to 2400 mm/year at Casermetta del M. Penna with precipitations evenly distributed over the year; maximum rainfall occurs in the autumn months whereas minimum takes place in the summer months. In the Upper Aveto Valley the rainfall trend increases with altitude: rainfall is more abundant along the Apennine ridge, in particular in the Mt. Penna and Mt. Aiona sector. Further supply depends on the condensation phenomena caused by the temperature range between the air, saturated with water vapour, and the bedrock joints near the ridge

(*hidden rainfalls*), in addition to snowfall between December and March. Annual mean snowfall is more than 100 cm; height and duration of snow cover on ground vary according to altitude and exposure.

Annual mean temperature ranges from 9.4°C at S. Stefano d'Aveto to 10.3°C at Giacopiane Dam. Distribution of the annual mean isotherms shows a zone with peak temperatures in the talweg: they tend to decrease with altitude.

Climatic analyses followed the Turc's formula for direct calculation of real evapotranspiration (Turc, 1954), given the annual mean precipitation and temperature. The annual mean low temperature determines a reduced evapotranspiration: a marked outflow is consequently produced, both above and under the ground, all over the year without periods of water deficit. The entire area features an extensive water supply as shown by a number of springs scattered all over the territory. The field-observations confirm the water-surplus calculated: a significant water flow occurs in the summer months and several springs are located both inside the large landslide bodies – near the hamlets of Magnasco and Cerisola and at the Lama Lake - and at higher altitudes, near the ridge. The surplus distribution suffers the annual rainfalls and, secondly, temperatures with the maximum values distributed along the Apennine ridge, particularly in the Mt. Penna and Mt. Aiona sector.

Particularly intense precipitations were recorded from October to November 2000: they were associated with a several situations of instability and geomorphological hazard that involved both slope portions and valley floor sectors. These hazards, characterized by high amounts of rainfall, concentrated over a short period, occasionally deteriorated pre-existing instability situations or triggered new instabilities, often damaging the existing man-made structures such as buildings, roads, waterworks mains, etc. in a number of urban areas.

Similar critical events frequently occur in this sector of the Upper Aveto Valley during the last century, underlining the relationship between critical weather events and main hydrogeological instability.

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## **DISTRIBUTION OF LANDSLIDING IN THE UPPER SCRIVIA VALLEY: GEOLOGICAL, GEOMORPHOLOGICAL AND CLIMATIC FACTORS**

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This work examines the distribution of landslides in the Ligurian part of the Scrivia Valley. This basin lies on the Po flank of the Northern Apennine, only few kilometres inland from the Ligurian Sea. A meteorological and climatic analysis was conducted, in particular to highlight the contributions of rainfall and water surplus. Landslides maps of IFFI (Italian Inventory of Landslides Phenomena by CNR - National Research Center - and Regione Liguria, Gorziglia *et al.*, 2006) and of PAI (Hydrogeological Asset of Po Basin by Po Basin Authority) were examined (Autorità di Bacino del Po, 2008), together with Planning documents of the municipalities of the valley and several works on safety and arrangements of landslides.

The distribution of landslides was mapped together with a geomorphological survey of the Scrivia Valley. Lastly this last map was compared with the distribution of landslides reported by municipalities to ORI (Observatory of Hydrogeological Risks of the Province of Genoa), relating situations of danger for artifacts or sites (Tomaselli & Falcioni, 2008).

Distribution of big landslides, deep-seated gravitational slope deformations (DSGSD), and ORI reports on landslides was compared with geological, geomorphological and climatic conditions.

While big landslides and DSGSD are mainly linked to geological and tectonic conditions, ORI landslides and reactivations of old phenomena seem to relate to water surplus.

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## **PERFORMANCE OF SUBMERGED BREAKWATERS FOR LEVANTO AND PIETRA LIGURE BEACHES PROTECTION**

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Coastal zones are dynamic and fragile systems where earth and sea interact and they represent an important source for worldwide economy. An in-depth knowledge of coastal hydro-dynamic and morpho-sedimentary mechanisms is fundamental to understand factors that could be harmful to littoral zones and to suggest interventions to preserve littoral areas. For these reasons it is necessary to study in detail the influence of man-made structures and beach behaviour during specific events.

Therefore, the object of this study is to compare two different littoral sectors in the Liguria region protected by submerged breakwaters, in order to emphasize analogies or discrepancies in their response to sea storms. The most interesting aspect of the research consists not only in the heavy structural differences between the analysed barriers, but also in the possibility to highlight hypothetical behaviour discrepancies between sectors of the same beach protected by different man-made structures, thus further analyse breakwater influence on beach behaviour.

In this study Levanto and Pietra Ligure littorals were considered. Levanto beach is a gravel pocket beach interrupted in its length by two groins. In order to further protect the beach a breakwater with standard structural characteristics was built in its central sector. This protection is approximately 65 m far from the shore and it extends for about 100 m alongshore. The structure crest is 7 m wide and it has an elevation of around 2 m below the low tide. There are two gaps about 35 m wide between the breakwater and the groins around it. Pietra Ligure beach is a gravel beach divided in two parts by a stream. All the beach is protected by groins that divide it in 5 cells. On three of them, submerged breakwaters were built with next generation technology. These breakwaters are 50 m far from the beach and they are wider than usual (30 m). Such innovative structural features allow to dissipate wave energy not only at the front of the barrier, thanks to waves reflection, but also at the top (Pilarczick, 2003). Another remarkable feature is the absence of gaps between the breakwaters and the groins around them. This aspect was designed to reduce rip currents formation and beach sediment transport towards the sea.

In order to carry out this study both video-monitoring (Holman & Stanley, 2007) and field survey were used. In particular, video-monitoring systems were very useful tools that allowed to focus the analysis on short term beach evolution. Instead, field data were used to perform a medium term study and to confirm information extrapolated from images.

Results showed further similarities in the morphodynamics of Levanto and Pietra Ligure beaches. With high wave energy, Levanto and Pietra Ligure beach behaviour was similar not only between protected and unprotected sectors of the same beach but also between cells protected by different types of breakwaters. In both cases the functionality of the structures decreases with increasing wave height, defeating the protective action of the barrier (Dean *et al.*, 1997; Browder *et al.*, 1996). This was demonstrated by comparable shoreline occurring in all cells considered in this study. In particular, with these conditions in Pietra Ligure rip currents formation was also reported.

This aspect was not detected with low wave height. In particular, in Levanto beach a salient formation was detected on the protected cell with low wave energy. This morphology formed thanks to nearshore circulation patterns that usually characterize beaches protected by submerged breakwaters (Ranasinghe & Turner, 2006; Thomalla & Vincent, 2003; Iskander *et al.*, 2007; Turner, 2006).

This morphology was not noticed on Pietra Ligure beach where probably the nearshore circulation pattern is different because of the absence of gaps between barriers and groins.

Thanks to the obtained information it is possible to state that, as regards breakwater functionality and efficacy in Levanto and Pietra Ligure beaches, the sectors protected by the barriers showed a behaviour analogous to unprotected ones. This suggested a partial ineffectiveness of the structures employed in littoral protection so on the whole the submerged breakwaters did not give the expected results.

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## **PEDOLANDSCAPE STUDIES FOR THE TERRITORIAL PLANNING OF THE TOWN OF SASSELLO (SV); SOME EXAMPLES AND GIS APPLICATIONS**

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In this paper a new working methodology is proposed, which allows to identify landscape units studying pedological characters of a given territory in order to provide the basic guidelines for its management.

The aim is therefore to contribute to the definition of methodological criteria to be used to determine the destination of use, stressing the importance of geopedology in the preliminary investigation for the planning landscape. This methodology was already used in a sample area in southern Sardinia (Orrù, 2007).

The study is applied in the sample area of the town of Sassello (SV).

Starting from the creation of a 1:10.000 map of the “Unit of Pedolandscape”, which are territorial units homogeneous in terms of soil and environment, the “Map of the landscapes” (1:10.000) and two derived map (1:30.000) have been elaborated; the first is the “Map of the Land Capability”, the second is the “Map of soil disposition to the growth of some Macrofungi”.

The used maps are basic raster regional technical maps 1:10.000 and technical regional maps DEM 1:5.000, elaborated in a GIS environment (ArcGIS 9.2) in TIN format; from this format it has been possible to produce the maps of altitude, exposure and slopes.

On the base of these derived maps, homogeneous areas from an environmental and physiography point of view have been delineated. Afterwards, geological, vegetational and land use maps have been analyzed and the correlation between these different themes allowed to create a preliminary map of pedolandscape units, which has been completed with the addition of the known characters for soils.

Thanks to this analysis the “Pedolandscape Map” of the area has been realized.

This map has allowed the assessment of the territory according to the standardized scheme of the Land Capability Classification (Klingebiel & Montgomery, 1961), usually used to classify the territory for large agro-pastoral system.

The classes of capability are defined by physical parameters of soil (soil depth, texture, surface stoniness, water retention, etc.) and by local environmental characteristics (slope, erosion risk, risk of flooding, etc.) in relation to the possible uses.

The central concept of the Land Capability refers mainly to the limitations of soil lodged against the agricultural generic use; limitations originate from both the quality of the soil and the characteristics of the environment in which it is inserted.

It assumes that lands with the higher ability to use, that fall into the lower classes, allow an intensive use for a reasonable period of time and for a wide range of uses that become active without degradation (sustainable use).

The other maps presented in this work are intended to reflect the ability of soil to the growth of some species of macrofungi.

Only those fungal types that, from the bibliography, were known to be present in the territory have been considered and edaphic requirements for their growth were analyzed (Zotti *et al.*, 2007).

Afterwards they were related to physico-chemical properties of soil, considering as the basic unit the pedolandscape; from the intersection of these data the map of the potential growth of epigeous fungi has been realized.

Finally, the interpretation and management of landscape has been deepened by developing an innovative methodology that allowed to identify different types of landscape, titled “Unit of Landscape”. These units are similar portions of territory, where the geopedological component is considered one of the determinant key of the landscape.

Moreover the soil characteristics, with the analysis of the present and past land use, have helped to define the possible sustainable uses of that portion of territory, the qualifying elements and detractors.

The map of the landscape could provide an useful support to identify, as well as the most scenic areas, zones with greater agricultural vocation and zones that, for various reasons, do not allow this use.

In conclusion, it expresses the effective assessment of landscape values, both of the soil and of the issues dictated by their continued use and deterioration.

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## **GEOMORPHOLOGICAL EVIDENCES OF PAST CATASTROPHIC EVENTS. A WAY TO REDUCE THE CURRENT COASTAL HAZARD?**

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Geomorphological evidences of past catastrophic events may represent an important tool to assess the current hazards, especially in coastal areas. In particular, large boulder deposits have often been used to determine wave heights, age of deposition, magnitude and frequency of extreme waves or tsunami events along the Mediterranean coasts (Mastronuzzi & Sansò, 2000; Scicchitano *et al.*, 2007; Vött *et al.*, 2009).

Nevertheless the Aegean Sea area is extremely susceptible to earthquakes and related tsunamis however few field evidences of the impacts of these catastrophic waves are reported in literature (Scheffers *et al.*, 2008). The present study was carried out in Lesbos Island (NE Aegean), the third largest Greek island covering an area of 1,630 km<sup>2</sup> and about 300 kilometers of coastline. In particular, the study area is located in the southern part of the island, between the villages of Plomari and Vatera. The coastline develops for about 30 km and is characterized by high cliffs and large sandy beaches, often interrupted by beachrocks outcrops. Here, a big amount of large boulders (up to almost 15 t) was individuated in four sites having different geomorphological and geological setting.

Direct observations on each boulder were carried out in order to measure it (size and weight, distance and elevation respect the shoreline) and to assess the pre-transport setting (underwater or sub-aerial position) (Nott, 2003). Moreover, a study of their long axis orientation and distribution was carried out in order to recognize the geographical origin of the waves. The Nott (Nott, 2003) approach was applied to understand if the boulders displacement was compatible with the local storm wave regime or if they were dislocated by tsunami events.

The orientation of elongated boulders allowed to detect two main provenience of the catastrophic waves, one comprised between 150N and 180N and the second between 210N and 240N. The study of wind-wave climate of the area induced to exclude a surge storm origin as cause of the large boulder accumulation. A tsunamitic origin was then attributed to the studied blocks.

Moreover, the bimodal distribution suggested that two different events could have affected the area and further datation on the fossil material found on the boulders (bryozoa, vermitids, serpulids) could confirm this hypothesis. The radiometric datation will also allow to confront the events with the historical

ones present in different Greek and Mediterranean tsunamis catalogues (Papadopoulos & Chalkis, 1984; Soloviev, 1990).

Other important result was the localisation of a deposit of a paleo-landslide in the coastal area of Melinta, a small village near Plomari. Here, blocks accumulation were found completely cemented inside a holocene beachrock. This area has been selected by the Plomari municipality for the installation of new telecommunication fixture and fittings and our result gave new data in terms of slopes stability.

In conclusion, this study provided a large amount of information concerning the current level of coastal hazard in southern Lesvos. The next step is to convert our results to recommendations for the local governments in order to plan different activities for the mitigation of the vulnerability especially in Plomari, the second largest town of the island, with about 5000 inhabitants.

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