SETTIMA GIORNATA RICERCA GIOVANI

31 Maggio 2011

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

Corso Europa 26 – Aula Perrier, ore 10:00

Seminari sulle attività di ricerca svolte dai dottorandi e assegnisti
nell'ambito delle Scienze della Terra

PROGRAMMA

SESSIONE 1
ASPETTI APPLICATIVI DELLE SCIENZE DELLA TERRA

Valentina Garavaglia (Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano): *Tree rings e processi geomorfologici: principi e nuove applicazioni*

Alessandro Sacchini: *Aspetti applicativi delle deformazioni gravitative profonde di versante nell'Appennino: il caso della Valle Scrivia (Liguria)*

Ada Lucchetti: *Una nuova classificazione geomeccanica per la valutazione della stabilità di coste rocciose*

Claudia Scopesi: *Metodi diretti ed indiretti per lo studio del trasporto solido nel bacino del torrente Teiro*

Alessio Cecchin: *Caratterizzazione mineralogica del litorale di Noli a seguito del ripascimento*

Daniele Rizzello: *Indagini geofisiche integrate del campo geotermico di Cisolok - Cisukarame (Indonesia)*

SESSIONE 2
SIMULAZIONE SPERIMENTALE DI PROCESSI NATURALI

Silvia Porro (Dipartimento di Scienze della terra "Ardito Desio", Università di Milano): *Applicazione del kinetic leaching test per la caratterizzazione geochimica della discarica mineraria di Hop, Rosia Montana, Romania*

Giulio Borghini: *L'evoluzione di bassa pressione del mantello litosferico attraverso lo studio combinato di campioni naturali e sperimentali*

Matteo Padovano: *Modelli analogici: un utile strumento per riprodurre le strutture geologiche*

Eva Azzali: *Precipitati ocracei formati durante processi di Acid Mine Drainage (AMD) mineralogia, chimica ed esperimenti di desorbimento*

SESSIONE 3
APPROCCIO COMPUTAZIONALE ALLO STUDIO DEI PROBLEMI DELLE SCIENZE DELLA TERRA

Marco Bruno (Dipartimento di Scienze Mineralogiche e Petrologiche, Università di Torino): *Struttura e proprietà termodinamiche delle superfici dei minerali: approccio empirico e quanto-meccanico*

Simone Barani: *Il terremoto dell'Aquila del 6 Aprile 2009 ha colmato un gap sismico? Risultati ottenuti dall'applicazione di un nuovo metodo a sismicità diffusa*

Cristina Malatesta: *Modelli numerici bidimensionali di un processo di subduzione interoceanica*

Davide Scafidi: *Può la tomografia sismica locale fare luce sui processi di subduzione nell'Appennino centro settentrionale?*

Donato Belmonte: *Proprietà termodinamiche della fase Anidra B ($Mg_{14}Si_5O_{24}$) e origine della discontinuità sismica dei 300 km nel mantello terrestre: uno studio ab initio*

OCHREOUS PRECIPITATES RELATED TO ACID MINE DRAINAGE (AMD) PROCESSES: MINERALOGY, CHEMISTRY, AND DESORPTION EXPERIMENTS

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The genesis of ochreous precipitates, in active and abandoned sulphide mines, is mainly due to Acid Mine Drainage (AMD) processes; AMD comprise a concatenated set of mineralogical reactions triggered by the supergenic interaction between sulphide mineralizations and atmospheric agents. The ochreous precipitates are composed by complex associations of Fe oxides *s.l.* (Fe-oxides, -oxyhydroxides and -oxyhydroxysulphates) which can contain goethite, lepidocrocite, jarosite, schwertmannite, 2-line and 6-line ferrihydrite. The genesis and stability of these mineralogical phases are controlled by continuous and cyclic variations of chemical-physical parameters of the circulating solutions (*p*H, Eh, saturation, activity and speciation of ions).

The AMD environments are commonly characterized by the diffuse circulation of Acid Sulphate Waters (ASW), *i.e.* strong acid waters (*p*H $\leq$ 3), with high sulphate concentrations; together with sulphates several ecotoxic metals are transported and selectively concentrated by ASW.

To study the role of the mineralogical phases on the fate of ecotoxic metals contained in ASW, eighteen samples of ochreous precipitates were taken near the lowest mine adits of the two mine sites with active and intense AMD processes: the Libiola Fe-Cu sulphides mine (Sestri Levante, Genova) and the Rosia Montana Au-Ag mine (Alba County, Romania). The Libiola mining area is characterized by a widespread circulation of strongly ASW containing very high levels of ecotoxic elements, deriving not only by the sulphide mineralizations (such as Cu, Zn, As) but also from host rocks and gangue minerals (such as Cr, V, Ni; Marescotti *et al*., 2008; Marescotti *et al.*, 2010). Also the Rosia Montana mining area is characterized by intense circulation of ASW with very high levels of ecotoxic elements (such as Cd, As, Cu, Pb e Zn; Bird *et al.*, 2005; Florea *et al.*, 2005); in this mining area contaminated waters mainly flow in the hydrographic basins of the Rosia and Abrud Rivers, which are indirect tributaries of the Danubio River.

In this work, we analyzed the mineralogy, the chemistry and the desorption capability of the ochreous precipitates sampled in the two mining sites. The mineralogical and chemical analyses evidenced significant differences between the Rosia Montana (RM) and the Libiola (L) samples: RM samples consist of a mixture (in different proportions) of jarosite [$A^{+}B^{3+}{}_{3}(SO_4)_2(OH)_6$; A = K, Na, Pb; B = Fe] and schwertmannite [$Fe_{16}O_{16}(OH)_{12}(SO_4)_2$] and are characterized by high content of Zn, V, Pb, As and Ag. The L samples are mainly composed by goethite (FeOOH), associated with minor jarosite, and they are strongly enriched in Cu, Cr, Ni and Co.

The different chemistry of RM and L samples appear to be related either to the different composition of the ore- gangue- and host-rocks-minerals weathered by ASW or to the different scavenging capacity of the mineral species within ochreous precipitates.

Finally, the kinetic batch desorption experiments were carried out to define the capability of the different mineralogical phases to release ionic species in solution. The preliminary results of these experiments, made at fixed *p*H (2, 4, 6, 8), showed trends that can be related in part to the bulk chemistry of the ochreous precipitates and in part to the different mineralogical composition (*i.e.* to the different adsorption/desorption capability of goethite, schwertmannite and jarosite).

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DID THE APRIL 6, 2009 L'AQUILA EARTHQUAKE FILL A SEISMIC GAP? RECENT FINDINGS FROM THE APPLICATION OF A NOVEL SMOOTHED SEISMICITY APPROACH

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The analysis of strain rates derived from different forms of data (seismological, geological, geodetic) is of crucial importance for a deeper understanding of the seismic process which, in turn, is fundamental for reliable earthquake forecasting and, possibly, prediction. In this study, I analyze the space-time evolution of seismic strain rates in the area struck by the April 6, 2009 L'Aquila earthquake (M_w = 6.3) and compare results with deformation rates from Global Position System (GPS) measurements (Barani & Eva, 2011). The aim is to provide new insights into the earthquake nature.

The L'Aquila earthquake took place in the Abruzzi Apennines, a mountain arc resulting from the superimposition of a NE-SW extensional tectonics (active since the Late Cenozoic) on a previous compressive deformation (*e.g.*, Galadini *et al.*, 2003). More specifically, it was associated with a SW-dipping normal fault, known as the Paganica fault (*e.g.*, Boncio *et al.*, 2011). The main shock was preceded by precursory earthquake activity beginning a few months before, increasing in the last ten days preceding the main shock (Papadopulos *et al.*, 2010), and terminating just some minutes before. Of note, the foreshock activity was clustered in a tight region (foreshock zone) where only a handful of mild events (no more than a tenth) were recorded in the last 3 decades.

Most of the study is concerned with the analysis and interpretation of seismic strain rates which were computed using the novel approach of Barani *et al.* (2010). Unlike standard approaches (*e.g.*, Anderson, 1986; Mazzotti & Adams, 2005), this method does not require the delineation of area or fault sources but implicitly incorporates them through the seismic catalogue. More precisely, it consists of calculating moment rates, $\dot{M}_o$, for each cell of a homogeneous grid covering the entire study area. Then, an elliptical kernel, with the major axis oriented parallel to the prevalent direction of the seismogenic faults (NW-SE) within the investigated region, is applied on them to determine smoothed $\dot{M}_o$ values. These latter are then converted into strain rates, $\dot{\varepsilon}$, by applying the Anderson formula (Anderson, 1979). Of note, the computation method adopted in this study implements a Monte Carlo simulation procedure to allow for the uncertainty affecting earthquake magnitude and seismogenic thickness.

Although both seismic and geodetic rates are affected by non-negligible uncertainties, results would indicate that the earthquake was originated in an area characterized by a deficit in the release of seismic deformation (seismic gap), most likely filled (at least to a large extent) by the earthquake itself. According to Habermann (1981), the discovered gap can be qualified as "mature" since different earthquake precursors (such as, intense foreshock activity, uranium groundwater anomalies, changes in radon content) can be identified.

Nevertheless, these findings are insufficient for a retrospective prediction of the investigated earthquake. At most, they allow us to make only qualitative observations concerning the likelihood of occurrence of the earthquake *ex post facto*.

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THERMODYNAMIC PROPERTIES OF PHASE ANHYDROUS B ($Mg_{14}Si_5O_{24}$) AND IMPLICATIONS FOR THE ORIGIN OF THE 300 KM DISCONTINUITY IN THE EARTH'S MANTLE: AN *AB INITIO* INVESTIGATION

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Phase anhydrous B (AnhB) is a dense anhydrous magnesium silicate with an ideal formula $Mg_{14}Si_5O_{24}$, possibly stable in the Earth's upper mantle and transition zone. The equilibrium boundary of the reaction Forsterite + Periclase = AnhB, which was determined for the first time in a multi-anvil apparatus by Ganguly & Frost (2006), has thrown new light on the stability of this phase at subsolidus mantle conditions. Following the way outlined by the experiments, a computational work began not only to check in an independent and self-consistent way the confidence of the experimental phase boundary, but also to assess the thermodynamic properties of the phase AnhB, not yet defined by calorimetric or other experimental (or computational) methods. The results of this study showed an excellent agreement with the experiments (Ottonello *et al.*, 2010), lending confidence to the thermodynamic properties calculated for this phase and encouraging us to investigate the possible seismic implications of the reaction.

In this contribution, *ab initio* quantum mechanical calculations of the elastic and seismic properties of the phase AnhB has been carried out using the CRYSTAL code (Dovesi *et al.*, 2010) and the hybrid B3LYP density functional method (Becke, 1993). The conformation of the single-crystal elastic constant tensor at several compressional states, corresponding to pressures up to 20 GPa, allows the calculation of the single-crystal seismic velocities and anisotropy. The elastic moduli of the aggregate, along with its longitudinal and shear

velocities, has been calculated by means of a Voigt-Reuss-Hill or Hashin-Shtrikman averaging scheme. The shear-wave impedance contrast associated with the reaction $5Mg_2SiO_4$ (Forsterite) + 4MgO (Periclase) = $Mg_{14}Si_5O_{24}$ (AnhB), which takes place at P-T conditions corresponding to the 300 km discontinuity in the Earth's mantle (the so-called X-discontinuity), seems to be compatible with that observed for this discontinuity (Bagley & Revenaugh, 2008). This kind of evidence, along with the fact that the thermodynamic properties of the phase AnhB are consistent with its stability at mantle P-T conditions, support the above reaction as a viable explanation for the origin of the X-discontinuity (at least in subduction zone environments).

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TRACING THE LOW-P EVOLUTION OF LITHOSPHERIC MANTLE BY A NATURAL AND EXPERIMENTAL COMBINED APPROACH

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The crystallization of plagioclase-bearing equilibrium assemblages in mantle peridotites is commonly considered witness of lithospheric mantle exhumation at shallow depth (*e.g.*, Rampone *et al.*, 1993; Ozawa & Takahashi, 1995; Newmann *et al.*, 1999). Experimental works have pointed out that at subsolidus conditions plagioclase lherzolite assemblages are stable at pressure below 1 GPa; in the CaO-MgO-Al_2O_3-SiO_2 (CMAS) system, thermodynamic mixing properties of both pyroxene solid solutions were explored and Al-isopleths of pyroxenes in plagioclase-facies lherzolite were also derived (*e.g.*, Gasparik, 1984). However, the compositional variations in plagioclase at varying P and T within the plagioclase stability field remained unexplored. On the other hand, a few studies on plagioclase peridotites from orogenic massifs (Ozawa & Takahashi, 1995; Newman *et al.*, 1999) evidenced the key role of plagioclase composition as a marker of varying P conditions in mantle peridotites. They documented a systematic increase of anorthite (An = Ca/(Ca+Na)) from core to rim of single plagioclase crystals (referred as "reverse zoning"), and interpreted it as the result of a continuous subsolidus reaction between two pyroxenes and spinel driven by progressive decompression and uplift of the peridotites.

Subsolidus experimental data in the complex chemical system Ti-Cr-Na-Fe-CMAS on depleted and fertile lherzolite compositions (Borghini *et al.*, 2010) have confirmed that the transition from spinel- to plagioclase-lherzolite is governed by a continuous reaction, resulting in systematic compositional variations in coexisting minerals at decreasing pressure within the plagioclase stability field, similar to what observed in equilibrated plagioclase peridotites. This potentially enables to trace the progressive decompressional evolution of the lithospheric mantle up to very low-pressure. In experiments, Ca-Na partitioning between plagioclase and clinopyroxene is strictly dependent on pressure; plagioclase records a significant anorthite content variation (An = 59-82) within a rather narrow range of pressure, and its composition at fixed P-T conditions is similar in

both fertile (FLZ) and depleted (DLZ) lherzolites. This indicates a striking correlation between plagioclase composition and P of equilibration in the shallow upper mantle, thus suggesting that plagioclase composition can represent an useful barometric marker. Here this inference is demonstrated by providing a direct comparison between i) microstructural-chemical features observed in natural plagioclase-facies recrystallized lherzolites from the External Liguride ophiolitic Unit (EL, Northern Apennine, Italy) and ii) the results of experiments on comparable lherzolite bulk compositions. At this purpose, new experiments on investigated peridotite bulks and on a new Na-rich peridotite composition, in order to define the influence of the bulk Na/Ca ratio on plagioclase chemistry, are in progress. Results of experiments have been fitted by multiple least-squares regression analysis to provide an expression for pressure as a function of plagioclase composition and temperature, in fertile lherzolite.

The studied plagioclase lherzolites show textural features and mineral compositional variations indicative of plagioclase-facies recrystallization (Rampone *et al.*, 1993, 1995). Detailed microanalytical work and textural observations have revealed systematic chemical zoning in texturally associated plagioclase and pyroxene neoblasts. Anorthite-reverse zoning in plagioclase is coupled to Al, Na, and Ca core-rim variations in granoblastic ortho- and clino- pyroxenes, documenting different stages of equilibration within the plagioclase-facies stability field. Agreement between compositional data in minerals from natural peridotite and experiments demonstrates the clear link between microstructural and mineral compositional data in plagioclase peridotites and their geobarometric evolution, previously inferred and now confirmed by our natural and experimental evidence. Application of this approach to the EL lherzolites provides equilibrium pressure of 0.7 and 0.3 GPa for the two recrystallization stages, indicating exhumation from about 22 to 9 km depth. Experimental results are also compared to mineral compositions from equilibrated plagioclase peridotites from different extensional settings to discuss the applicability of the proposed geobarometric equation. Experimental Na-Ca plag-cpx partitioning can be used to test the attainment of chemical equilibrium in neoblastic plagioclase-bearing mantle assemblages, thus enlarging the applicability of this approach in equilibrated plagioclase peridotites of different origins.

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STRUCTURE AND THERMODYNAMICAL PROPERTIES OF THE MINERAL SURFACES: EMPIRICAL AND QUANTUM-MECHANICAL APPROACHES

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The real surface profile of a (*hkl*) face rarely coincides with the ideal *hkl* lattice plane. As a matter of fact, the *hkl* plane is a geometrical abstraction of the crystal structure, while to generate the corresponding surface profile, one has to consider the face character: flat (F), stepped (S) or kinked (K), according to the Hartman-Perdok theory (Hartman & Perdok, 1955), along with its interactions with the mother phase.

According to the Tasker's rules (Tasker, 1979), three types of surfaces in ionic or partly ionic crystal can be identified. Type I consists of neutral planes with both anions and cations. Type II consists of charged planes arranged symmetrically so that there is no dipole moment perpendicular to the unit cell. The type III surface is charged and there is a perpendicular dipole moment. These surfaces have infinite surface energies (or very large surface energies for finite crystals) and produce a polarising electric field in the bulk. An electrostatic argument therefore indicates that such surfaces cannot exist. To explain the presence of unstable surfaces of Type III, either at equilibrium or during growth, one has to invoke (i) modifications at the atomic level induced by adsorption of foreign substances and/or (ii) a reconstruction of the surfaces to cancel out the 2D-dipole arrays, and/or, as it was suggested for some forms of covalent phases, (iii) a rearrangement of the electronic structure resulting in an effective charge transfer between the polar surfaces.

The characterization of the surfaces is done by determining their (relaxed) structures and surface free energies (γ) by means of empirical (force field) and *ab initio* (DFT level, B3LYP Hamiltonian) calculations, and by considering the 2D slab mode. The slice energies (SE), and the end chain energies (ECE) of the different Periodic Bound Chains (PBC's) running in the interplanar distance d_{hkl} permitted by the extinction rules, are also calculated. The *ab initio* calculations were performed by using the CRYSTAL06 package (Dovesi *et al.*, 2006), whereas the empirical calculations were done with the GULP code (Gale, 1997).

A detailed discussion on γ is done. Indeed, the surface free energy is a fundamental thermodynamical quantity needed to determine the equilibrium morphology of a crystal, according to the Gibbs-Wulf theorem. The definitions of *unrelaxed* and *relaxed* surface energies will be given, and the different methodologies to calculate them will be explained. Furthermore, even the definitions of SE and ECE will be given, as well as and the calculation strategies employed to determine such quantities.

Finally, examples of Type I and III surfaces, with particular regard to the relaxed structures and the surface energies of the {10.4}, {01.2}, {00.1} forms of calcite ($CaCO_3$), and the {10.4} and {00.1} forms of nitratine ($NaNO_3$), will be discussed.

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SEDIMENTOLOGICAL AND MINERALOGICAL ANALYSES CONDUCTED ON THE BEACH OF NOLI AFTER THE NOURISHMENT

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The increasing value of the beaches and the requalification of many sectors of urban waterfront required many studies and interventions in coast defence and in re-naturalization of protected coast (Aucelli *et al*., 2006).

Currently, about 30% of the Italian coast is in erosion despite the presence of man made structures built to protect it. These structures not only did not stop the erosion but resulted in a landscape degradation and in a reduction of the economical value of the beaches.

A method to compensate the loss of sediments, related to the actions made in the inland of the river basin, is represented by the beach nourishment. An important aspect in a nourishment project is the mineralogical composition of the materials over then quantity and grain-size. In fact one of the key points of the D.G.R. n. 1553/2001 (Regione Liguria) concerns the definition of the mineralogical characteristics and compatibility (colour) of the sediments with the touristic-recreative use and the landscape aspect of the beach.

In this work the attention is paid to the sedimentological and mineralogical analysis performed on Noli beach (SV) following the nourishment projects did between Capo Noli and Rio Scaglia.

Historically, this sector was subjected to several moments of retreat or advancement of the shoreline due to emplacement of material from several quartzite's and limestone's quarries of the area. These works were able to stabilize the shoreline but, the closing of the mining activities at the end of 1950 and the further widening of the Via Aurelia up to a width of 7-10 m, at the expense of the beach, caused the missing balance and the erosion of the beach (Fierro *et al.*, 2010).

From 1960 to 1980, thousands of cubic meters of material (sands, rocks, etc.) were periodically poured at the Colonia Cantore from earthworks made for the costruction of the Enel Central of Vado, as well as from excavation of highway, sewage tunnels, and demolition waste. These nourishment activities produced a marked advancement of the shoreline in the extreme south sector, between Capo Noli and the Colonia Cantore, and an equilibrium in the north side (between the Colonia Cantore and Vescovado groin). In these years three groins were built and these are still present in the northern sector. Moreover, between 1982 and 2002, 30,000 cubic meters of coarse material were poured. This sediment came from disused FFSS areas of Noli, from cleanliness of the Quiliano river, and from Mezzeno River floods (a mixed of gravel and sand). Finally, in 2005, as part of the research program COFIN 2004 "Pilot cases of nourishment in Liguria: the compatibility of materials from quarries and evaluating the effictivenessy of operations", 7,000 cubic meters of material from mining activities were poured. All these nourishment projects have enabled the stability of the beach giving it a whitish colour.

In this area the drift is oriented northward, therefore part of the material was poured in the Colonia Cantore site whereas in the NE sector the nourishment was done through four temporary barkers groins. This material was composed by quartzitic rocks (lower Trias) ascribed to the "Quartzite of Ponte di Nava Formation" (Mt. Carmo-Rialto Unit); the rocks were quartz-sandstones conglomerate, mostly with a siliceous cement, and they were variable in color from white to yellowish and locally up to grey or green (Bisi, 2005). The special texture and tenacity of this lithotype are predisposing factors for the natural formation of fine gravel and sand as a consequence of natural erosion processes, as it can be seen at the local dismissed quarries. The chemical characterization has been performed following the ARPAL protocol for sampling and analysis; the results of the analyses, made at the Laboratory C.P.G. (Carcare, SV), evidenced that all the samples were within the limits of the ARPAL protocol. The crushed and treated quarried material had an average diameter of 12.4 mm and consisted of: 85.21% gravel, 10.97% sand and 3.82% silt (Bisi, 2005).

The aims of this study were both the mineralogical characterization of sediments and the evaluation of the effectiveness of the nourishment project after two years. Twelve samples were taken from shore and twenty-two samples from shoreface, at a depth of -5 and -10 m. Sedimentological analysis were made on all samples whereas the mineralogical analysis were made only on the most representative samples of the shore.

Sedimentological analysis showed that in the backshore the medium-coarse sands prevailed, in the foreshore the fine sands, in the shoreface (until at the -10 m isobath) the gravels and the coarse sands whereas below -10 m the fine sands and silts.

Mineralogical analysis (optical microscopy and X-ray diffraction) showed that the sediment was primarily composed by mineral species derived both from the nourishments and from erosion of the Capo Noli cliff (dolomite, quartz, biotite, muscovite, plagioclase, feldspar); other minerals, such as serpentine-group minerals, amphiboles, hematite, and garnets, probably derived from the old earthworks made for the tunnels of the Genova-Ventimiglia highway in the Voltri Massif.

Two years after the nourishment program, the beach reached its natural stable profile. In fact, the field surveys showed that the littoral accreted in comparison with the original position before the intervention; therefore the poured material was in stable condition, which probably resulted from a good distribution that has also fuelled the shoreface.

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TREE RINGS AND GEOMORPHIC PROCESSES: PRINCIPLES AND NEW APPLICATIONS

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Dendrochronology, *i.e.* the study of annual tree rings formed by plants growing in temperate climates (Schweingruber, 1996), is a dating method often applied to ecology, climatology, glaciology, geomorphology, archaeology, etc.

In more details, dendrogeomorphology is based on the capacity of trees to record external disturbances, such as geomorphic events, in their tree-ring series. Trunks, roots or branches damaged by geomorphic processes represent an important source of information: growth anomalies related to the occurrence of events can be dated using dendrochronological techniques and the year, or even the season, in which the disturbance occurred, can be detected. Dendrogeomorphology represents the most accurate method for reconstructing past geomorphic

disturbances over several centuries (Bollschweiler *et al.*, 2008), increasing the knowledge about past and thus improving the possibilities to estimate future tendencies.

In mountain regions, geomorphic processes are widespread phenomena and may affect inhabited areas. As a consequence, the understanding of their spatial and temporal distribution as well as of their behaviour can contribute to hazard and risk mitigation.

Moreover, processes such as debris-flows and snow avalanches often interact with tourist activities augmenting the necessity to disseminate their knowledge, with the aim of decrease tourist vulnerability.

In this study, tree rings are proposed as a method for reconstructing past events (for dating processes, for estimating their spatial and temporal distribution, and their frequency) and as a discipline interacting with classic monitoring systems.

The proposed investigations refer to different environments (from Alps to Apennine, from mountain regions to coastal ones), highlighting the possibility to apply dendrochronology to several case studies and geomorphic contexts.

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A NEW GEOMECHANICAL CLASSIFICATION FOR THE ROCKY COAST STABILITY EVALUATION

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Seacliffs have been long considered conservative forms with unchanging landscape due to their aspect and slow evolution, and it is only during the last few decades that the interest in these landforms has increased. Infact, recent scientific outcomes in this field show that cliff development is less evident in high coasts compared to low coasts, but it is more rapid and unpredictable.

Seacliffs morphology is similar to that of natural slope, but with the additional stress of wave action. Their geomorphological evolution depends on the rock mass strength and on the wave features, whose interaction overlays weathering and man's actions. Therefore seacliff investigation is difficult due to the lack of a satisfying scientific approach.

This study has been applied to the southern slope of the Portofino Promontory (eastern Liguria, Italy), which is characterized by high rocky coasts with stability problems. The seacliffs, which are particularly exposed to wave action, are occasionally higher than 50 m and their walls have almost vertical inclination.

The rock mass quality may be assessed by geomechanical classifications, whereas wave action must be evaluated by considering the factors that regulate the interaction between waves and seacliffs.

Geomechanical classifications have long provided products for surveying *in situ* input parameters, which have been used for their relative simplicity and rapidity. These classifications have also been successfully applied to the slope stability investigation. In this case, their usefulness depends on wide areas of analysis where, first of all, an extensive but synthetic evaluation of rock mass quality must be provided in relation to slope stability to determine the most hazardous areas where further specific and detailed investigation should be carried out.

The most frequently used geomechanical classifications have been primarily assessed in order to select the most suitable for evaluating the high rocky coast stability. The classification systems Rock Mass Rating (RMR) of Bieniawski, Rock Mass Strength (RMS) of Selby, Slope Mass Rating (SMR) of Romana and Geological Strength Index (GSI) of Marinos & Hoek have been ultimately selected from those available that have been presented over the last twenty five years.

These classifications are not entirely satisfying when applied to seacliff stability as this depends on dynamic stresses due to wave action at the foot of the scarp. The wave motion pressure depends on a few factors such as wave height, sounding morphology and wave front direction which is influenced by the prevailing wind. Therefore, a seacliff stability evaluation following a geomechanical classification applied to a rock slope can be carried out by introducing a factor representing the wave motion action. Based on the outcomes of a comparative analysis, as well as various authors' suggestions, a seacliff classification has been developed by modifying the Slope Mass Rating, *i.e.* the system that is specifically used for assessing the rocky slopes stability. Infact, it also includes joint orientation which is a basic item for identifying possible kinematic mechanisms along the scarp.

The new classification is dubbed Sea Cliff Mass Rating (SCMR) and introduces a new parameter to take into account the pressure of the waves against the cliff. The factor F4 of Romana concerning the method of excavation has been replaced by the $F4_m$ parameter indicating the rocky wall condition in relation to possible anthropogenic actions that could interfere with the cliff. The effect of wave motion has been assessed by introducing an M factor, dependent on the wave energy, on the rock slope inclination and on the wave direction with respect to the coastline.

The SCMR classification has been applied to the hard rock conglomerate cliffs of the Portofino Promontory: its active seacliffs are suitable to carry out a sample study of rocky walls. The SMR and SCMR index ratings have been obtained and initial results proved the validity of the classification presented. The outcomes allowed the substantiation of the wave action influence on seacliff stability, thus confirming that the stability evaluation of a cliff requires also an understanding of the wave motion affecting it.

2D NUMERICAL MODELING OF AN INTRAOCEANIC SUBDUCTION PROCESS

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Among the several 2D numerical models, that were produced in the last decade, regarding subduction zones (*e.g.* Burov *et al.*, 2001; Gerya *et al.*, 2002; Gorczyk *et al*., 2007; Yamato *et al*., 2007; Warren *et al*., 2008; Faccenda *et al*., 2009; Roda *et al*., 2010), only few dealed with the theme of an intraoceanic subduction process (Gerya *et al*. 2002; Gorczyk *et al*., 2007).

Gerya *et al*. (2002) considered a self-organizing large-scale flow pattern and temperature field in subduction zones. They showed that the subduction of a layered oceanic crust produces a serpentinite subduction channel in which low-viscosity material undergoes forced return flow; in particular, burial and exhumation are affected by the progressive hydration of the mantle wedge.

According to the model by Gorczyk *et al*. (2007), the intraoceanic subduction produces a serpentinite channel in which slab slices are mixed. The authors show that buoyancy triggers the rise of a top serpentinite mélange and a deep seated (100-150 km) mélange. The buoyancy forces developed due to the contrast between dry mantle wedge peridotites and the partially hydrated peridotites.

Conversely to Gerya *et al*. (2002) and Gorczyk *et al*. (2007), the models that I present show a subduction zone developing in a narrow oceanic basin (600 km-wide) surrounded by continental margins. The introduction of continental crust in the models allows to define which is its influence on subduction dynamics. These models are based on the modified code I2VIS (Gerya & Yuen, 2003). A self-organization of the subduction zone is allowed and the subduction/exhumation processes are therefore free to evolve. The simulations are designed in a 4000 km × 200 km box in which computational finite-difference nodes are distributed on an irregular rectangular 2001 × 2001 grid. The reproduced oceanic lithosphere is similar to that generated at present slow and ultra-slow spreading ridges: the serpentinized lithospheric mantle includes discrete gabbros bodies and is covered by a discontinuous basaltic layer. The dehydration of the slab produces a viscous serpentinite channel in the mantle wedge; its geometry is controlled by key parameters like the rheology of serpentinite, the slab dip, the age and structure of incoming oceanic lithosphere. Rheology of serpentinite also controls strongly important features such as the mixing and exhumation mechanisms of subducted slab and sediments. The relationships between slab and mantle wedge serpentinites have also been highlighted, providing further evidences on the nature of serpenitinite mélanges.

Finally, the volcanic activity developing on the upper plate during subduction was analyzed. In general, it has been noticed that volcanism is poorly affected by serpentine rheology. The steep and fast slabs are responsible of young volcanism and young oceanic lithosphere produces early volcanic activity that is closer to the trench compared to old slabs.

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ANALOGUE MODELS: USEFUL TOOLS TO REPRODUCE GEOLOGICAL STRUCTURES

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The first attempts to reproduce in laboratory geological structures observable on the field have been performed by Ramberg (1955). His pioneeristic work has been followed in the years by an increasing number of publications, in which the use of analogue models, in comparison with natural geological structures, became quickly widespread.

The modern approach to the analogue models requires a good knowledge of the rheological behaviour of rocks, changing with pressure, temperature and strain conditions. The rheological behaviour recorded by rocks must be reproduced in the model, choosing appropriate rheological parameters (density and/or viscosity) for the analogue materials. Their choice, together with the setting of the environmental conditions (temperature, pressure and strain rate), directly affects the final reliability of the analogue models.

One of the biggest problems, while reproducing an analogue model, is represented by the scale factor; in fact, the real properties observable in nature (size, viscosity, density, etc.) are rarely reproducible in laboratory. This problem can be partially solved if, instead of considering the absolute values of the investigated properties, the relative ones are chosen (*i.e.* two rock layers of 1 and 3 metres in thickness can be reproduced by the superposition of two layers of analogue materials having a thickness of 1 and 3 mm respectively).

If the target of an analogue model is to reproduce ductile structures occurring in natural deformed rocks, the most used materials consist of plasticines with a power-law (non Newtonian) behaviour, where viscosity changes as a function of temperature and strain rate. Conversely, the structures mainly driven by density contrast (for example uplift of salt diapirs), are usually reproduced using materials with a Newtonian behaviour, where the value of viscosity is constant. The brittle structures, occurring in the upper crust (fractures and faults), are modelled by using sand layers.

In this work, some practical examples of analogue models, employing sand and/or plasticines as analogue materials, will be described and compared. In particular, the attention will be focused on: modelling the development of pop-up structures in the upper crust (McClay & Bonora, 2001); reproducing the emplacement of granitic bodies with a tabular shape (Dietl & Koyi, 2008); modelling fault reactivations and tectonic inversions (Dubois *et al.*, 2002); modelling chocolate tablet boudins structures (Kraus, 2009); modelling the emplacement of high temperature crustal rocks in compressive settings (Padovano, 2011).

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KINETIC LEACHING TEST FOR THE GEOCHEMICAL CHARACTERIZATION OF THE HOP WASTE-ROCK DUMP (ROSIA MONTANA, ROMANIA)

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Mining industry is an essential activity that provides the raw material for society but, unless adequate precautions are taken, it can be accompanied by serious negative impacts on the environment and human health. Major impacts, occurring during and after mining operations, are associated with the release of ecotoxic elements from mine waste to meteoric water. Abandoned sulphide mining areas are of particularly concern because water-rock interaction can trigger off Acid Mine Dranaige (AMD) formation, with consequent acidification of circulating waters and release of hazardous elements in the environment.

An important tool for geochemical assessment of abandoned mine-waste dumps is a quick, cost-effective and qualitative leach procedure, designed by the U.S. Environmental Protection Agency (1994) to evaluate the impact of contaminated earth material on groundwater. This kinetic test provides an insight into the behaviour of the waste-rocks during the interaction with meteoric water and gives useful indication of the potential chemical composition of the run-off from the weathered surface of mining areas.

In this study, the Modified E.P.A. Method 1312 (SPLP) was applied to assess the acid generation potential and the chemical composition of the run-off water from the Hop waste-rock dump, at the Rosia Montana ancient mining area (Apuseni Mountains, Romania). This hydrothermal ore deposit is hosted in andesites and dacites of Neogene age, piercing the prevolcanic sedimentary basement as breccia pipes (Roşu *et al*., 2004). They host polymetallic sulphides and Au-Ag-Te mineralisations, present in epithermal veins, mineralized phreatomagmatic breccias and stockworks (Wallier *et al*., 2006). The ore deposit was mined both in underground and in open pit for more than 2000 years and intensive alteration due to AMD processes is testified by acid sulphate waters.

The eastern side of the Hop waste dump (2.5 ha area), where the waste has been piled up between 1998 and 2000 from Cetate open-pit, was subdivided in a 30×30 m grid to obtain a final collection of 27 samples. SPLS test was applied to 20 of them: the < 2 mm fraction of the solid material was shook for 18 hours in a rotary agitator, together with a slightly acidified de-ionized water, designed to simulate natural precipitation (water:solid ratio 20:1). Total Cu, Zn and As content of the filtered solution was analyzed by ICP-AES, whereas a little aliquot of the unfiltered leached water was taken for pH, electrical conductivity and sulphate concentration analyses.

The results showed that eco-toxic elements content in filtered solutions is generally low: Cu ranges from 0 to 98 ppb (mean 14), Zn ranges from 21 to 570 ppb (mean 155) and As ranges from 1 to 7 ppb (mean 2.5). These data are in agreement with the results of bulk waste-rock material chemical composition, whose metal concentrations are in the range of tens of ppm with the exception of As, that shows a content one order of magnitude higher (Azzali *et al*., 2010). The *p*H values vary greatly (from 2.9 to 8.9) according to mineralogical and geochemical composition of the waste material. The sulphate content is highly variable, ranging from 13.5 to 475 ppm and exceeding the European limit for drinking waters (250 ppm, EU Directive 1998/83 CE) in 6 samples. A significant positive relationship between sulphate concentration and EC was found.

This test allowed to assert that Hop waste-rocks can generate acid run-off waters with hazardous sulphate concentrations, according to their mineralogical and geochemical composition. Their arsenic release in meteoric water is always lower than the European limit for drinking water (10 ppb, EU Directive 1998/83 CE), despite its high content in solid samples. Moreover these results confirm that the Modified E.P.A. Method 1312 (SPLP) is an affective and rapid screening tool for the qualitative characterization of contaminated lands.

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INTEGRATED GEOPHYSICAL SURVEY OF A GEOTHERMAL FIELD IN WEST JAVA (INDONESIA)

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A critical component in understanding the hydrothermal properties of complex geothermal reservoirs is the technology to provide images of the subsurface structures, which control geothermal fluid flow. Electrical resistivity/conductivity is a primary physical property of the Earth strongly influenced by hydrothermal processes present in geothermal reservoirs. If mapped, resistivity can be used to infer untapped fracture systems and regions of increased permeability and fluid content, as well as conductive alteration of minerals (clays, etc.) due to induced fracturing arising from hydraulic simulation of the reservoir (Newman *et al*., 2005).

Aimed at the reconstruction of the subsurface and structural setting together with the identification of horizons, which could host geothermal reservoirs, a series of magnetotelluric and time domain electromagnetic sounding has been carried out, together with gravity measurements, in a geothermal area, located in the West Java Province, Indonesia.

Magnetotelluric survey has revealed significant differences in resistivity structure between two main geothermal zones. In the South West zone, the conductive layer (clay cap) is rather discontinuous and shallow. The resistivity maintains relatively moderate, with values of 10-50 ohm*m, to depth of about 2000 m below the surface. This agrees with a moderate alteration to large depth due to flow of fluid with relatively low temperatures. A possible explanation of this geoelectric setting is groundwater flow through discrete fractures zones scattered within a basement. The thermal manifestations might occur through a major fracture zone. The North East zone presents a well discernible and thick (up to 500 m) conductive layer (< 10 ohm*m), interpretable as a cap rock. This layer is present next to the hot springs area and around it. Beneath the conductive layer, the resistivity increases with depth more rapidly than in the SW zone. At depth of 1000-1500 m below the surface, resistivity shows average values larger than 50-100 ohm*m. This resistivity pattern supports a hydraulic model through a diffuse flow of thermal groundwater. Sudden lateral changes in the resistivity in correspondence of a valley in the NE zone support the presence of a near vertical fault, which might control the groundwater upflow. The Bouguer gravity anomaly is of relatively small magnitude, so that the presence of buried high-density bodies, which could act as heat sources for the hydrothermal systems, has to be excluded. The main positive anomaly, observed at the SW edge of the investigated zone, could be related to an

intrusive granodioritic body, also encountered by drilling, and the associated volcanic rocks cropping out and it may also reflect the border of an uplifted structure. In the above-quoted NE zone valley, the gravity map puts into evidence the possible presence of a fault roughly NNE/SSW directed.

In synthesis, the different resistivity structure between the two zones is compatible with the conclusion of the previous geochemical study by, stating that two main geothermal sites belong to totally distinct geothermal systems. Also in relation to the reservoir temperatures estimated with geothermometers, the resistivity pattern appears more interesting at and around the NE geothermal sector.

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DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS IN THE LIGURIAN APENNINES: THE CASE-STUDY OF UPPER SCRIVIA VALLEY

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The deep-seated gravitational slope deformations (DSGSD) are large-scale instabilities affecting the whole system ridge-slope-valley floor. They have been recognized and studied particularly in the major mountain ranges (Jahn, 1964; Zischinsky, 1969; Nemcock, 1972), and above all in the Alps, since the last decades of the last century, for their impressive effects on morphology (Dramis, 1984; Crosta, 1996; Crosta *et al*., 2008) and buildings and infrastructures (Kilburn & Petley, 2003). More recent studies recognized several situations related to DSGSD in the Apennines (Cancelli & Pellegrini, 1987; Dramis *et al*., 1987; Crescenti *et al*., 1994; Faccini *et al.*, 2009).

In particular, the Scrivia Valley has been recognized as a case study for such phenomena, due to its geological conditions (Cancelli & Chinaglia, 1994). The Scrivia valley is characterized by a higher percentage of landslide areas than regional and national average and the presence of several huge landslides and palaeolandslides. The causes of these landslides have been investigated from five main factors of slope instability: geological, geomorphological, hydrogeological, climatic and anthropogenic.

The landslide distribution is represented by the combination of almost all the factors with the prevalence of geological and geomorphological and less importance of human factors. Based on many geomorphological evidences (such as closed depressions, trenches, double ridges, reverse slope, para-karst landforms), a great amount of DSGSD was found. They include almost all the huge landslides and palaeolandslides mapped on site and most of the current situations of instability.

The overlapping of hard and weak rocks, the complex tectonics and the neotectonic uplifting are all predisposing and triggering factors for this valley dynamics. The fact that a large valley area is characterized by DSGSD, from one hand raises important implications for planning land use and, on the other hand, for monitoring slope movements because of size and special dynamics of these phenomena.

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CAN LOCAL EARTHQUAKE TOMOGRAPHY SETTLE THE MATTER ABOUT SUBDUCTION IN THE NORTHERN AND CENTRAL APENNINES?

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Seismic tomography is the most powerful tool to investigate large volumes of the earth. The three dimensional inversion of teleseismic earthquakes provides poorly detailed information on large and deep bodies, whereas local earthquake tomography has the potential to display smaller anomalies but down to a depth limited by the deeper earthquakes included in the inversion.

Although many geological, geophysical and geodynamical studies have been conducted on the Italian area, there are still open questions, and different models have been proposed to explain the present-day structural setting. Some of the most debated questions are the presence or not of continuous subduction under the Apennines, and the presence or not of a slab detachment in the northern or in the central part of the Apenninic chain. The absence of a continuous, high velocity body beneath the Apennines has been interpreted by some researchers (Wortel & Spakman, 2000) as an evidence of the detachment of the Apenninic slab. According to this view the Apenninic slab is expected to be inactive whether the Ionian lithosphere subducting underneath Calabria is considered to be on the verge of detaching or just detached. Other researchers (Guegen *et al.*, 1998), however, suggest that a fairly continuous and fast slab exists beneath the Apennines and the Calabrian arc. Different geodynamical models have also been proposed for the Tyrrhenian area considering it as an active (Faccenna *et al.*, 1996) or as a passive margin (Lavecchia *et al*., 2003; Scalera, 2005).

In previous works, our research group has conducted several seismic tomographies with both techniques in the search of the geometry, size and extension with depth of the subduction under the Italian peninsula. While

the images resulting from teleseismic data were clearly showing a subducting slab under the Calabrian arc, they were not conclusive for the rest of the Apennines since they were showing, only in the Northern sector, a likely subduction in the shallower part apparently detached from other high velocities body in the deeper zone. At that stage it was not possible to distinguish between thrust and subduction due to the poor horizontal resolution of the applied methodology. More recently, a local earthquake tomography (Scafidi *et al.*, 2009) has given details about this shallower sector but again was not able to clearly display a subducting slab. The main limitation of this tomography is the lack of seismic events deeper than 60-70 km under the northern and central Apennines. The absence of seismicity itself can be not considered an evidence of non-subduction, as some authors showed that different rheological behaviours of the continental versus oceanic lithosphere can account for the shallower and subcrustal seismicity below the northern Apennines with respect to deeper and more intense seismicity below the Calabrian arc. In particular, the low seismicity or aseismic behaviour of orogenic roots or slabs may, in some cases, be ascribed to a ductile deformation of quartz-feldspar rich subducting continental lithosphere, rather than to the absence of active subduction (Carminati *et al.*, 2002). In practice, the kind of seismicity may depend on reasons different from the subduction, and should not be considered evidence for the presence of it.

In order to analyze in more details this apparent discrepancy, a new seismic tomography is presented in this work. A very dense grid, the selection of a smaller area to be investigated and the addition of new data partly improved the results, which anyway cannot go beyond the maximum depth of seismic events. Several tests have been conducted in order to understand the resolving power of the tomographic study. They show the capacity of such a tomographic setup to depict a subduction if it is present, and not to show an untrue subduction if it is not present, almost in the first 80 km of depth.

Analyzing different cross sections of these enhanced resolution tomography results, we do not see any slab in the northern-central Apennines in the first 100 km depth. The downgoing material (Adriatic plate) of this area has a rather low dip angle, as also partly shown by the distribution of the (few) deep seismic events. Along the central and also the northern part of the Apennines there are more overlapping geometries than subducting geometries.

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DIRECT AND INDIRECT METHODS FOR THE STUDY OF SOLID TRANSPORT IN THE TORRENTE TEIRO BASIN

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The sediments production in a river basin derives almost always from a phase of erosion that occurs mainly on the slopes, and then spreads with a phase of transport in the main watercourse (river).

The study and the quantification of a river sediment transport (both suspended and bed-material sediments) by direct and indirect measurements, is a fundamental datum for studying the dynamics of a river bed and beaches' feeding.

Thanks to these data it would be possible, for example, to reduce the risk of inundation in a catchment basin.

The biggest part of a sediment responsible of a rise in inundation risk derives from the soil erosion of slope. Thanks to this working method it would be possible both, to estimate soil erosion in each part of the basin by indirect methods, and to quantify that portion which falls into the river by direct measurements.

This new procedure is applied to the Torrente Teiro basin, which extends for 28 square kilometres in the province of Savona, between the municipality of Stella and Varazze, and it is representative for many Ligurian basins.

The indirect method applied in the Torrente Teiro basin is a G.I.S. analysis that allows to delineate E.R.U. (Erosion Response Unit; Maerker *et al.*, 2001). Homogeneous erosion process entities are carried out using the semiautomatic classification method of GIS system: the physiographic parameters like geology, geomorphology, land use, morphology and pedology are overlaid in a G.I.S. system (ArcGis 9.2) and reclassified to obtain "terrain units" that express homogeneous information on erosion processes in act (Pelacani *et al.*, 2006).

The direct method applied in the basin is the sediment sampling in several points of the stream. In collaboration with "Regione Liguria" it has been chosen to use an instrument that measures water level in section and, through a sampling pump, that surveys sediment suspended transport.

Moreover, several "time-integrate" sediment samplers (Phillips *et al.*, 2000) will be used in some points of the Torrente Teiro tributary streams.

The sampler can be deployed unattended in small streams to collect time-integrated suspended sediment samples. In laboratory tests involving chemically dispersed sediment, the sampler collected a maximum of 71% of the input sample mass (Phillips *et al.*, 2000).

Thanks to the integration of both direct and indirect methods, a quantification of sediment transport in the TorrenteTeiro basin is supplied.

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