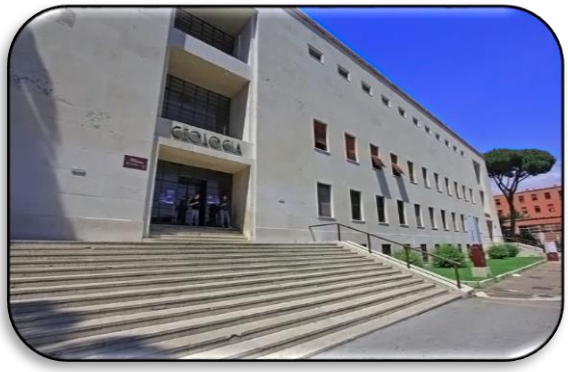
# Roma Chiama Roma

*First Edition*

**8:15-18:40**

**Dipartimento di Scienze, Università Roma Tre**

**Largo San Leonardo Murialdo 1 – aula M1 Nuovo Blocco Aule**



**I dottorandi e neo-dottori di Ricerca in Scienze della Terra delle due Università di Roma s'incontrano per la prima volta in un giorno dedicato a presentazioni orali, posters, dibattiti e scambi scientifici**

**Organizzazione a cura dei coordinatori e co-coordinatori dei Dottorati di Ricerca in Scienze della Terra delle Università Sapienza e Roma Tre**

ROMA TRE
UNIVERSITÀ DEGLI STUDI

SCIENZE
Dipartimento di Eccellenza

SAPIENZA
UNIVERSITÀ DI ROMA

## Program

- 8:15 - 8:20 – **Welcome and introduction**
- 8:20 - 9:00 – **Keynote: *Chris Marone*** (Sapienza and Pennsylvania State University) **"Predictability of lab earthquakes"**
- 9:00 - 9:35 – **Short oral presentations** (PhD students from Sapienza and Roma Tre University, cycle XXXV): *Atoubat, Bigaroni, Conte, Gori, Liberatore, Moschini, Mattia*
- 9:35 - 10:15 – **Short oral presentations** (PhD students from Roma Tre University, cycle XXXIV): *Clementucci, Di Fiore, Galli, Jozinovic, Scaccia, Scarani, Todrani, Vergara*
- 10:15 - 10:30 – **Coffee break**
- 10:30 - 11:20 – **Poster sessions** (PhD students from Roma Tre University, cycle XXXIV)
- 11:20 - 12:30 – **Short oral presentations** (PhD students from Sapienza University, cycles, XXXIV and XXXIII)*: D'Ambrosio, Innamorati, Monaco, Palummo, Proietti, Verticchio, Bonechi, Delchiaro, Franchini, Iacobucci, Moricca, Ruggieri*
- 12:30 - 13:30 – **Lunch**
- 13:30 - 14:10 – **Keynote: *Federico Rossetti*** (Roma Tre University) **"Orogeny: a metamorphic perspective"**
- 14:10 - 15:10 – **Poster sessions** (PhD students from Sapienza University, cycles XXXV, XXXIV and XXXIII)
- 15:10 - 16:55 – **Oral presentations** (PhD students from Sapienza and Roma Tre University, cycles XXXII): *Briganti, Di Stefano, Galetto, Mercuri, Racano, Valiante, Silleni*
- 16:55 - 17:10 – **Coffee break**
- 17:10 - 17:50 – **Short oral presentations** (PhD students from Roma Tre University, cycles XXXIII): *Abassi, Decaro, Fioramonti, Frontoni, Galdenzi, Magrini, Marrone, Reitano*
- 17:50 - 18:30 – **Poster session** (PhD students from Roma Tre University)
- 18:30 - 18:40 – **Final remarks**

**Organization:**

Paolo Ballato, Sveva Corrado, Paola Tuccimei (University of Roma Tre)
Marta Della Seta, Silvio Mollo, Fabio Trippetta (La Sapienza University)

# KEYNOTES

## Predictability of lab earthquakes

***Chris Marone***

*Dipartimento di Scienze della Terra, La Sapienza Università di Roma, Italy*

*Pennsylvania State University*

Efforts to forecast and predict earthquakes are hampered by a lack of reliable lab and field observations. However, recent advances show: 1) clear and consistent precursors prior to earthquake-like failure in the lab and 2) that lab earthquakes can be predicted using machine learning (ML). These works show that stick-slip failure events –the lab equivalent of earthquakes– are preceded by a cascade of micro-failure events that radiate elastic energy in a manner that foretells catastrophic failure. Remarkably, ML predicts the failure time and in some cases the magnitude of lab earthquakes. Here, I summarize recent lab observations of precursors to failure for the full spectrum of modes from stable creep to slow labquakes, and elastodynamic rupture. Remarkably, this range of events can be predicted using ML techniques to analyze acoustic emissions emanating from the fault.

## Orogeny: a metamorphic perspective

**Federico Rossetti**

*Dipartimento di Scienze, Università Roma Tre.*

Metamorphic rocks retain the environmental conditions that deviate from the steady-state thermal structure of the lithosphere. The inversion of the P-T-t-deformation histories as derived from the study of the metamorphic rocks in orogenic suture zones has thus the potential to reconstruct the evolution of the Earth's crust in space and time (assembly and differentiation). A reappraisal of the contribution of metamorphic geology to the understanding of the lithosphere evolution and geodynamics is firstly presented, with a window on the early Earth. This is followed by a review of the subduction zone metamorphism, by presenting the controlling factors (intrinsic and extrinsic), the representative rock associations (HP and UHP series) and the metamorphic gradients expected during orogenic construction and destruction (collapse).

**CYCLE XXXV**

# Structural styles of the External Rif and Flysch Domain (Rif belt, northern Morocco) through thermal maturity and structural data

**Atouabat Achraf[1],**

Tutors, co-tutors: Corrado Sveva.[1], Mohn G.[2], Schito Andrea[1]

*[1]Dipartimento di Scienze, Università degli Studi Roma Tre, Rome, Italy*

*[2]Laboratoire Géosciences et Environnement (GEC), Université de Cergy-Pontoise, Neuville-sur-Oise, France*

Located in the northern Morocco, the Rif belt represents the western edge of the Maghrebides system. This domain underwent a significant Cenozoic alpine compressional deformation, due to the collisional process between the north African margin and the southern margin of the exotic AlKaPeCa terrains, with major events, leading to a nappe stacking structuration, recorded during the Miocene.

This contribution aims to characterize the main tectonic mechanisms driving the evolution of the Rifain wedge, its burial-exhumation paths and to understand the role of the architecture of the north African passive paleo-margin on the Rif belt structuration. Hereafter, the work focuses mainly on the Flysch domain, originated from the Maghrebian branch of the Tethys, that was ensuring the connection between the Central Atlantic and the alpine oceans from Jurassic to Paleogene times, and the External domain (namely Intrarif, Mesorif and Prerif) that are belonging to different parts of the former north African margin.

To define the thrust sheet stacking pattern and their burial-exhumation paths, three regional transects crossing the orogenic wedge from the Flyschs to the Prerif Units will be produced.The methodological approach consists in combining petrography and Raman micro-spectroscopy on organic matter and 1D thermal modelling, together with field structural survey.

The thermal maturity data combined with 1D thermal modelling will provide a new vision on the structural evolution of the western part of the Rif belt. Moreover, it will be possible to define the rate of shortening and by contrast the reconstruction of the non-eroded wedge, and to propose a new geological restoration with respect to the Mesozoic North African margin structural original setting.

# Laboratory experiments of fluid injection–induced seismicity: via Vp/Vs, dilation and fluid pressure monitoring

**Bigaroni Nico**

Tutor: Scuderi Marco Maria

*Dipartimento di Scienze della Terra, La Sapienza Università di Roma*

Fluid overpressure has been proposed as one of the primary mechanisms that facilitate earthquake slip along tectonic faults. However, elastic dislocation theory combined with friction laws suggests that fluid overpressure may inhibit the dynamic instabilities that result in earthquakes. In fact, rateand state-friction parameters do change with increasing fluid pressure and a comprehensive characterization of these parameters is fundamental for better assessing the role of fluid pressure in natural and human induced earthquakes. This controversy poses a serious problem in our understanding of earthquake physics, with severe implications for both natural and human-induced seismic hazard. However, currently, there are only a few systematic studies of the role of fluid pressure under controlled, laboratory conditions for which the evolution of friction parameters and slip stability can be deduced. To address this controversy, I will monitor the fault slip evolution of laboratory creep experiments, during fluid pressurization of simulated fault gouges. Monitoring will be performed by simultaneously recording Vp/Vs, fault opening, fault slip, fluid pressure and flow rate. In this way, systematic information on the physical processes that occur during fluid pressurization will be obtained, such as, experimental evidence of "dilation hardening" behavior. Such an approach is fundamental to understanding how the rate- and state-friction parameters (a-b and Dc) vary during the increase in fluid pressure. The experiments will be conducted, in a double direct shear configuration within a true-triaxial pressure vessel, on samples with low permeability of Opalinus Clay from the natural laboratory of Mont Terri (Switzerland). Here an international team of researchers will conduct, in parallel with my laboratory experiments, new fluid injection experiments on a decametric scale, in order to understand if Opalinus Clay is suitable for the disposal of radioactive waste. In this way it will also be possible the uncommon experimental comparison between the variation of mechanical and acoustic data in experiments conducted under the same conditions but at different scales. During my PhD I will also conduct experiments on calcite powder and crystalline rocks, in order to study how fluid overpressure affects the permeability and stability of faults located in the main reservoir rocks. In addition, through the use of different injection rates, I will be able to simulate different injection histories that can be representative of a vast spectrum of natural cases (like tidal perturbation). Ultimately, will be proposed a physics-based models that use new friction laws including the effects of fluid pressure and its rate of change on friction parameters, may help anticipate fault response to injection based on modeling and monitoring of seismicity, seismic velocity changes, and deformation.

**Keywords**: induced seismicity, frictional stability, fluid pressure, creep experiments, slow slip

# Confined volatiles (H2O and CO2) in amorphous silica: implications for terrestrial and extraterrestrial materials.

**Alessandra Conte**[1]

Tutors: Giancarlo Della Ventura[1], Benjamin Rondeau[2]

Co-tutors: Federico Lucci [1], Boris Chauviré[2]

[1]*Department of Science, University of Roma Tre*

[2]*University of Nantes*

Opaline silica is a poorly crystalline or amorphous variety of hydrated silica ($SiO_2 \cdot nH_2O$), which can be found in a broad range of geological environments, always related to the availability of an aqueous fluid. Its structure consists in a compact arrangement of spheres with various degrees of structural order, and it typically contains abundant $H_2O$/OH sometimes associated with $CO_2$.

The degree of crystallinity of opals can be considered as the intermediate stage between hydrated siliceous glasses (formed by the direct quenching of hydrated magmatic melts) and microcrystalline quartz. While hydrated siliceous glasses can retain just small percentages of isolated water ($H_2O$ or OH groups) the structure and porosity of opaline silica allows the confinement of water ($H_2O$, OH groups and Si-OH bonds) even up to 15 wt% located in empty spaces and interstitial films. Structure, microstructure and geological settings have a great influence in the typology of water and its content inside opaline silica, which can be identified by its infrared signature. Thus the observation of the water-related absorption of hydrated silica can be used not only to determine the structure of silica but also reflects the geological environment of formation. Even though numerous studies have been already carried out on amorphous silica and its properties, we still need to understand some key features such as: 1) the diffusion of volatiles under high pressure and high temperature conditions; 2) the definition of absorption coefficients for quantitative analysis of H and C; 3) the effects from UV exposure on the structure and properties of opaline silica. The latter point is very important due to the recent discovery of opaline silica on Mars by the Curiosity Rover, which its considered to be a witness for the presence of water in extra-terrestrial environments. Moreover in literature it is known that opals turn into crystalline quartz under high pressure, however at present the process and the P-T conditions to which this transformation takes place are unknown. The aim of this PhD project is to characterize the physical behavior of confined volatile molecules ($H_2O$/OH/$CO_2$) in different specimens of silica with various degrees of crystallinity (opal-A, opal-CT, chalcedony) and of different origins, in order to correlate them with the geological conditions of formation. To do so, the samples will be examined by using a multi-technical approach, combining XRD, SEM-EMPA, Raman and FTIR spectroscopy. Understanding the dynamics of the entrapping processes of volatiles in silica has important bearings not only in Earth Science, but also for a broad range of disciplines including electronics and technology.

**Keywords**: opaline silica; confined volatiles; geological context; hydrated silica; spectroscopy.

# Groundwater and seismicity relationship: hydrogeological monitoring to identify "hydrosensitive sites" in central-southern Italy

**Francesca Gori[1],**

Tutors, co-tutors: Marco Petitta[1], Marino Domenico Barberio[1], Carlo Doglioni[1,2] and Antonio Caracausi[3]

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*[3] Istituto Nazionale di Geofisica e Vulcanologia – INGV, Palermo*

This research is part of the PON project of the INGV hydrogeochemical monitoring. The aim of this study is to expand our understanding of the cause-effect relationship between groundwater and seismicity to define "hydrosensitive" sites in central-southern Italy. In order to achieve the goal, a hydrogeological and hydrogeochemical characterization of the main springs in central-southern Apennines will be carried out with a seismic and geodetic characterization of the study area. A systematic study of the hydrogeological and hydrogeochemical parameters potentially influenced by seismic activity (piezometric levels, temperature, pH, electrical conductivity, chemical and isotopic composition of groundwater and dissolved and free gases) is proposed and a comparative and integrated analysis will allow to verify existence and modalities of cause-effect relationship between the hydrogeological and hydrogeochemical signals with the seismic and geodetic ones. In some specific sites, among those previously pre-selected by PON, the role of fluids will be analyzed in a tectonic-structural framework to develop optimally this multidisciplinary study and the dynamics related to groundwater circulation and water-gas interactions will be also defined. In fact this research activity will provide a detailed degassing investigation of mantle-derived fluids through lithospheric discontinuities and in particular the diffuse $CO_2$ degassing in tectonically active areas by groundwater will be monitored through the isotopic study of $\delta^{13}C$, as well as helium, for the evaluation of gasses origin potential depth. The innovation of this project is based on a multi-parameter monitoring in different sites and on data cross analysis. For the first time laboratories will be carried on field and high frequency data will be measured and transferred remotely in order to characterize dynamics and time evolution of processes in relation to seismicity of the central-southern Apennines region. Data processing will allow to identify periodicity, trends and relationship with local, seasonal and anthropic conditions and potential characteristic trends that occur in relation to crustal strain. Regarding seismic and geodetic investigation, earthquakes recorded by the National Seismic Network will be considered and specific GPS data sequences related to short time intervals will be elaborated to study correlations between transient signals of potential significant earthquakes and potential recorded hydrogeological anomalies. On the basis of obtained results, the influence of seismic cycle on water chemical-physical characteristics will be verified and the potential variations in the time series will be detected. This project has also has an application aimed at assessing the availability and quality of water resource, focusing on the hydrodynamic modifications that fractured aquifers undergo. Hence, monitoring can contribute to the implementation of the Water Safety Plan to make drinking water safer and to face the problem of emerging contaminants.

**Keywords:** Earthquake hydrogeology, Central-southern Italy, hydrogeochemistry, gas-geochemistry, isotopes

# The Arabian-Anatolian collision system: evidence and causes for Holocene-to-Recent differential vertical movements at the southern margin of the Anatolian Plate

**Marco Liberatore**

Tutor: Domenico Cosentino

*Dipartimento di Scienze, Università Roma Tre.*

Three main plates are involved in the Arabo-Anatolian collisional zone: *Arabia* is moving to the north towards *Eurasia* while the *Anatolian plate*, between the twos, is moving rapidly to W-SW in a geodynamic process called extrusion. Evidence of such tectonical escape is the seismicity, marked also by some huge earthquakes (Mw>7.0), along two major strike-slip fault systems: the northern one and the eastern one. It is commonly thought that all the deformation in this context is accommodated by these two strike-slip structures, so that the Anatolian plate is moving coherently as a rigid block. But the rigid block model is just an oversimplification, as testified, for instance, by the recent uplift history of the southern margin of the *Central Anatolian Plateau (CAP)*. Recent works demonstrate a very rapid and intense uplift of the southern margin of the CAP: a Pleistocene (ca. 450 kyrs) coastline is in fact now at 1500 m a.s.l. Uplift history, lately reconstructed, shows a non-linear velocity curve, bell shaped, peaking at ca. 200 kyrs (MIS 7) with a value of more than 3 mm/yr. After the major peak, velocity started falling to the actual estimated value of 1.2-1.5 mm/yr. This value comes from the dating of Holocene raised coastlines from some spots along the coast of Turkey between *Antalya* and *Adalia* but needs to be better constrained both in space and intensity. Although the actual vertical velocity is smaller than before, it is very different from the other adjacent areas. In fact, archaeological evidences and geological markers show for Cyprus no sign for a relevant uplift during Holocene time (no more than few tens of centimetres). On the other hand, the same kind of markers are showing, for the sector to the west of the CAP (W of Antalya), an active process of subsidence (ca. -1mm/yr). This emerging situation, with adjacent blocks moving differently one from each other (although they are standing on the same overriding plate of the subduction system), needs to be faced in order to better define it in terms of space, time and intensity. The other question is how the differential movement is being accommodating: in this sense, probably, an important role is played by two major tectonical structures, the *Isparta Transform Fault* to the west of the CAP and the *Ecemis Fault Zone* from south to the east of it. Geological, archaeological and geomorphological markers of the paleo-shorelines will be used to determine the recent vertical velocity pattern, especially on the CAP southern margin where published data are lacking. Conversely, geodetic analysis and seismology will be used to assess the geometry, kinematic and stress field associated to the already cited faults in order to understand if the slip on them can explain this complex geodynamic picture.

**Keywords:** Central Anatolian Plateau (CAP), Holocene, Uplift, Differential vertical velocity pattern

# Volcanic hazard assessment at Mt. Etna: a time-integrated, polybaric and polythermal perspective.

**Piergiorgio Moschini**

Tutor: Mario Gaeta

*Dipartimento di Scienze della Terra – Sapienza Università di Roma*

With my PhD project, I will provide new tools for interpreting polybaric-polythermal changes in the plumbing system of Mt. Etna performing microanalyses of major/trace elements in natural/synthetic clinopyroxene, plagioclase and coexisting glasses. With the application of thermobarometers, hygrometers and geospeedometers it will be possible to characterise the intensive variables involved in the evolution of both crystals and plumbing system. The application of a novel chronometric model (NIDIS) on the crystals will be useful to retrieve the timescales of pre-eruptive processes that will be integrated with monitoring signals allowing to provide a conceptual model of the temporal evolution of magma dynamics.

**Keywords**: Clinopyroxene; Thermobarometry, hygrometry and geospeedometry; Major and trace elements partitioning; NIDIS model; Mt.Etna volcano

# Subsoil and groundwater contamination by NAPLs. Isotopic dating and evaluation of natural attenuation of contaminants

**Martina Mattia**[1]

Tutor: Paola Tuccimei[1]

Co-tutors: Michele Soligo[1]; Gianfranco Galli[2]

[1]*Università "Roma Tre", Dipartimento di Scienze,*

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NAPLs (Non- Aqueous Phase Liquids), are a group of chemicals, characterized by low water solubility and poor miscibility. There are several NAPLs, such as chlorinated solvents, hydrocarbons and their derivatives (diesel, kerosene, etc.). These substances have a high environmental impact and, unfortunately, the number of accidents involving spills, both on land and at sea, has multiplied over time as a result of their increasing use in modern industrialised societies, especially in oil derivatives related activities. When spills or leaks occur, these substances may be absorbed by the soil and may reach the groundwater, causing contamination. The management of contaminated sites remains a major problem today, mainly due to both the lack of standardized, legal methods to estimate the age of contaminant release and the shortage of reliable forecasts on response times of individual sites to remediation procedures. The aim of this research project is to develop an integrated and standardized method. This will include dating of the spills and leaks, spatial-temporal monitoring of the concentration and distribution of the pollutant, and the evaluation of natural attenuation processes of NAPL concentrations in sites with different geological substrates. The studies will be applied to a polluted site in Rome, where multiple spills have occurred over time. The first phase will focus on analysis, in order to determine the age of contamination by using radiometric methods based fundamentally on the decay of radio isotopes in water-enriched and soil samples taken from areas affected by oil and gas extraction. Subsequently, the validity and effectiveness of a new analytical procedure will be developed and deepened. This procedure involves the study of the degradation of NAPLs in soil using possible biomarkers in order to determine with greater certainty the age of the contamination and to estimate the natural attenuation times of these pollutants. The dating analyses complement the observation and monitoring of the spills. The project will utilise geochemical tracer, primarily radon gas and specifically the radon deficit technique, in effort to identify the contaminant in the vadose zone of a polluted aquifer. Finally, where possible, the concentration and distribution of other gases, such as VOCs, CO2, CH4 and H2S, will be assessed as to better characterize the radon deficiency in the examined area, and thus facilitate a more comprehensive study of the polluted site. This project is of extreme importance as it will determine a more precise and accurate estimation of the natural attenuation times of the pollutant, enabling the costs of remediation operations to be assessed more effectively. Furthermore, the knowledge of the age of contamination will be very important in many legal disputes for the allocation of environmental recovery costs to those responsible for pollution.

**Keywords**: NAPLs, pollution, monitoring, natural attenuation, remediation

**Cycle XXXIV**

# Deciphering mantle contribution on surface uplift in the Anti-Atlas and Western Meseta area (Morocco)

**Romano Clementucci**[1]

Tutor: Paolo Ballato[1]

Co-tutors: Lionel Siame [2], Claudio Faccenna[1]

[1]*Dipartimento di Scienze, Università Roma Tre.*

[2]*Aix-Marseille Université, CNRS-IRD-Collège de France, UM 34 CEREGE.*

The high topography of the Atlas-Meseta system (Morocco) represents a combination of localized crustal shortening and thickening processes induced by plate convergence and regional dynamic uplift associated with the flow of the asthenoshperic mantle. Although the magnitude and timing of large-scale dynamic uplift is poorly constrained, the occurrence of uplifted shallow-water marine deposits in the Middle Atlas Mountains and in the western Meseta indicates that surface uplift must have started after the Late Miocene (Messinian) at rates of 0.1 to 0.2 mm $yr^{-1}$. This event is still recorded by transient channel profiles and the relief distribution in the catchments of the Atlas-Meseta system.

In order to investigate the regional spatio-temporal distribution and the rates of dynamic surface uplift we have selected key areas in the Anti-Atlas Mountains and the Western Maroccan Meseta where Cenozoic crustal shortening and thickening processes are virtually absent. This approach offers the possibility to isolate and estimate the dynamic component of uplfit from present-day topography. In particular, we have combined geomorphic analysis of stream profiles with in situ-produced cosmogenic concentrations ($^{10}Be$, $^{26}Al$) in river sediments and bedrock surfaces corresponding to relict landscape upstream of knickpoints. Our catchment-mean erosion rates allow us to quantitatively constrain the landscape evolution and hence to unravel the contribution of regional surface uplift on mountain building processes in Morocco during the Plio-Quaternary.

**Keywords**: Cosmogenic dating, Dynamic topography, Atlas-Meseta system, Transient river profiles, Mountain building

# The role of undercooling and strain rate on the syn-eruptive rheological evolution of the magma feeding the Pollena eruption of Somma-Vesuvius (Campania; Italy)

**Fabrizio Di Fiore**[1]

Tutor: Alessandro Vona[1]

Co-tutors: Silvio Mollo [2] & Claudia Romano[1]

[1]*Dipartimento di Scienze, Università Roma Tre.*

[2]*Dipartimento di Scienze della Terra – Sapienza Università di Roma*

Subplinian eruptions are generally characterized by unsteadiness in magma discharge due to decoupling between magma supply at depth and magma discharge at the surface. The result is the formation of short-lived, oscillating convective columns, repeated transitions from sustained to collapsing column and time-breaks of days/weeks between different eruptive pulses.

The Pollena Subplinian eruption of Somma-Vesuvius (472 CE) is an archetype of this kind of volcanic event. Previous studies recognized three main eruptive phases related to changes in the eruptive processes and/or to relative changes of magma composition (from phonolite to phonotephrite). In contrast with the classical assumption of a direct proportionality between melt silica content (i.e. viscosity) and explosivity, the highest energy event involves the phonotephritic magma. Some authors invoked a dominant role of the rheological evolution of the rising magma along the conduit and in particular microlite crystallization seems to be the pivotal factor controlling the increasing explosivity.

In order to model the syn-eruptive evolution of magma rheology (i.e. change in viscosity), we conducted a series of experiments act to investigate the effects of undercooling and strain rate on the crystallization kinetics. The crystal-bearing rheology of the magma was determined by isothermal crystallization experiments in a concentric cylinder set-up. Starting from a superliquidus state (1300 °C) of magma, the experiments were performed under variable degrees of undercooling (120-150 °C) and strain rates (1-10 $s^{-1}$), the latter reproduced through the stirring of the melt.

Preliminary results show that both degree of undercooling and deformation rate strongly control the kinetics of the crystallization process. Shorter incubation time for crystal nucleation and higher nuclei density are observed with increasing undercooling and/or flow conditions, ultimately influencing the solidification ability of the melt. Notably, dynamic conditions enhance the mobility (by diffusional transport) of chemical elements in the melt and their availability at the growing crystal surface, hence promoting crystal growth. The effect of dynamic crystallization is commonly overlooked in the modeling of volcanic conduit dynamics, but could have played a key role on the syn-eruptive rheological change of unsteady Subplinian eruptions during the Pollena event.

# Title: "Mapping buried Holocene paleo-riverbeds and seismic bedrock's morphology of Biferno river coastal plain using geophysical prospections"

**Giorgia Galli**[1]

Tutor: Giuseppe Della Monica[1]

Co-tutors: Carmen Rosskopf[2], Marilena Cozzolino[2]

[1]*Dipartimento di Scienze, Università Roma Tre.*

[2]*Università del Molise*

The aim of this project is to fill the knowledge gap regarding the evolution of Biferno River coastal plain (Molise, Italy) by combining various geophysical techniques.

Previous researches allowed reaching a detailed description of the lithologies and an accurate chronological reconstruction and localization of different fluvial terraces studying the numerous boreholes carried out for the construction of the nearby railway (Amorosi et al. 2016; Bracone et al. 2012). In addition, further studies reconstruct the Biferno paleo-riverbeds' trend through the analysis of historical maps, the remote sensing of satellite and aerial images, the interpretation of geomorphological and archaeological-finds data (Bracone et al. 2016).

In this work ERT (shallow depth) and EMI (very shallow depth) prospections have been applied to reconstruct and identify paleo-riverbeds trends in the Holocene shallow subsurface deposits performing while HVSR single station ambient seismic noise analysis has been implemented to define and to reconstruct the morphology of the Plio-Pleistocene deep bedrock's trend (Nakamura 1989), until now often hypothesized. The comparison and integration of the different geophysical techniques contributes to having a better overall survey campaigns' result and it allows making evaluations that are more complete on the different parameters that describe the same physical situation.

**Keywords:** applied geophysics, paleo-riverbed, Biferno coastal plain, electric and electromagnetic methods, HVSR technique

# Machine learning in seismology

**Dario Jozinović**[1]

Tutor: Fabio Cammarano[1]

Co-tutor: Alberto Michelini[2]

[1]*Dipartimento di Scienze, Università Roma Tre.*

[2]*INGV Rome*

Machine learning algorithms build a mathematical model based on sample (training) data,in order to make predictions or decisions without being explicitly programmed to perform the task. Deep learning, as a subset of the neural network approach to machine learning, is a case of machine learning especially suited for high dimensional input variables, e.g. images or seismic waveforms. Lot of training data are necessary to train a machine learning model well. Seismic stations provide us a large number of seismic waveform data recorded every day, which can then be used to train a deep learning algorithm for the problems where an analytical solution is hard to produce. In this research project the focus will be on developing an earthquake early warning system, with the aim of estimating ground shaking and its impact in an area not yet reached by the seismic wavefield, from the partial waveforms recorded at the stations in the area, few seconds after the first P arrivals. At the beginning the project is focused on developing the algorithms for predicting peak ground motions from partial waveforms of earthquakes. After the algorithms are developed, the project will focus on updating the algorithms to be able to estimate the impact of the predicted ground shaking. The developed algorithms could then be used to develop software for assistance in providing pre-earthquake and post-earthquake response to the scientific community and the broader public.

The goal of the developed algorithms and the software will be to answer the following questions rapidly: *The shaking will exceed, or not, a certain threshold beyond which there may be damage? How many people are likely to be affected to varying degrees of shaking? How much infrastructural damage could be expected?*

**Keywords**: Machine Learning, Deep Learning, Shaking intensity, Damage, Early Warning

# Plio-Quaternary evolution of the central Apennines: the case of the Medium-Upper Aniene River Valley (Latium, central Italy)

**David Scaccia**

Tutor: Paola Molin

Co-tutor: Michele Soligo

*Dipartimento di Scienze, Università Roma Tre*

The Apennines Chain has been affected by a regional uplift since the Upper Pliocene, with an increase in uplift rate since the end of Lower Pleistocene. In the last decades, many attempts have been made to estimate the timing and magnitude of the topographic growth affecting the chain. Estimations of past surface uplift in orogen interiors are difficult for the lack of geomorphic markers with known original elevation such as marine terraces. For this reason it is crucial to exploit continental indicators of past base levels such as fluvial terraces and planation surfaces. In particular fluvial terraces record changes in fluvial dynamics (aggradation and incision) depending on the interaction between climate and tectonics. Moreover, when carbonate aquifers are present, climate influences the formation of fresh-water travertines which, for this reason, are widely studied to investigate Quaternary climate changes. In this framework the Medium-Upper Aniene River Valley (Central Italy) represents a good testing site to investigate the interaction between surface processes, climate, and tectonics in the context of the Apennines topographic growth. Indeed this portion of the Aniene River Valley is characterized by widespread well-exposed Quaternary deposits consisting in wide fluvial terraces and fresh-water travertines alternated in places with lacustrine and volcanic deposits. Despite the well exposure of outcrops and the dateability of travertines and volcanic deposits, poor efforts have been done in order to correlate the Quaternary deposits along the Aniene River Valley nor to investigate the interaction between deposition, tectonics, and climate. In order to tackle this problem we perform a multidisciplinary approach comprising a topography and river network GIS investigation, a field survey campaign to map the Quaternary deposits along the valley, a geochemical and geochronological analysis of travertine deposits, and a paleontological analysis of lacustrine deposits outcropping in the study area. The results allow to reconstruct the Plio-Quaternary evolution of the Medium-Upper Aniene River Valley in the framework of the uplifting and extending Apennines chain.

**Keywords**: Apennines, uplift, topography, fluvial terraces, travertines

# Estimating fast cooling rates recorded by glass-forming melts: a flash DSC calibration

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The study of the thermal evolution of pyroclasts is fundamental for the understanding of volcanological processes. For instance, the thermal evolution of pyroclastic density currents directly influences their final run out distance. Similarly, the heat transfer between hot particles and colder ambient air in a convective plume strongly controls the cloud evolution. Since the heat amount available in the system strongly impacts on deposit characteristics, the study of pyroclastic material is fundamental to get information on their thermal history and ultimately reconstruct eruptive dynamics.

In the last decade, few studies dealt with relaxation geospeedometry techniques using a Differential Scanning Calorimeter (DSC) on volcanic materials. This methodology allows to access the thermal history of glassy phases, by revealing the kinetics of cooling across the glass transition. Common DSC devices explore limited cooling rates (below 0.5 K/s) and often need large extrapolations to be applied to cooling rates affecting natural pyroclastic materials.

In this study we introduce the use of a new device, the Flash-DSC, only applied so far in the field of material sciences. Through flash DSC analysis it is possible to widely increase the investigated cooling rates ranging from 3 to 30000 K/s. Therefore, it represents a major improvement for the study of fast- and hyper-quenched glasses, and better captures the cooling rates experienced by volcanic materials following both sub-aerial and submarine eruptions.

We conducted Flash-DSC tests using the so-called "unified area-matching approach". This methodology uses two heating cycles performed at the same heating rate (in this case 1000 K/s). The second cycle is a cooling-heating matching cycle (always at 1000 K/s). The area-difference between measured heat capacities of the two cycles can be used to determine the fictive temperature of the naturally-cooled glass. A simple relation links the fictive temperature to melt viscosity and cooling rate across glass transition. Therefore, if the viscosity is known, the cooling rate can be retrieved.

Preliminary analysis on standard and synthetic glasses (DGG-1, Diopside and Phosphate) allowed to model successfully cooling rates up to 1000 K/s representing a remarkable improvement for relaxation geospeedometry methodology, with promising implications for the study of volcanological processes and materials, which will be the object of future investigations.

**Keywords**: cooling rate; fast scanning calorimetry; flash DSC; glass; thermal history.

# Structural and Paleomagnetic evidences from intra-continental Mula Basin in SE Tibet

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The Cenozoic collision of Indian and Eurasian plates caused the formation of the Tibetan Plateau, one of the most deformed regions on the Earth. The continuous convergence induced the propagation of the stresses inland causing the extrusion of the Tibetan crust around the East Himalayan Syntaxis (EHS) toward the Yunnan and Indochina regions. Previous geodynamic models suggest that the Tibetan crust was fragmented into "lithospheric mega-blocks" or "microplates", bounded by continental-scale strike-slip faults. In this work, we report on the paleomagnetism of 29 Eocene red bed sites (288 samples) from the intra-continental Mula Basin, in SE Tibet (29.1°N, 100.3°E). The basin is ~ 40 km long and 8 km wide, bounded by two thrust faults. Hidden strike-slip faults have been also described. A Characteristic Remanent Magnetization (ChRM) was isolated in 8 sites, whereas a high-temperature magnetization component was isolated between 550 and 690°C for 13 paleomagnetic sites. A positive fold test at 99% level of significance on the whole dataset confirms the primary origin of the acquired magnetization. Anisotropy of magnetic susceptibility (AMS) of sampled rocks highlights a typical magnetic fabric of weakly deformed sediments with an oblate-to-prolate susceptibility ellipsoid. In addition, the lineation is generally horizontal and parallel to the main structural trend of the basin. Vertical-axis rotation calculated with respect to Eurasia show that the northern portion of the basin is characterized by clockwise (CW) rotation (up to 190° ± 14°), instead the southern part is characterized by counterclockwise (CCW) rotation (up to 30° ± 9°). Sites from the central portion of the basin show both CW rotation (up to 36° ± 8°) and no rotation at all. Such a pattern suggests that the upper crust is fragmented in small blocks (maximum 5 km wide). However, considering 14 paleomagnetic sites characterized by a declination deviation lower then ±40° from 180°, the tilt-corrected site-mean declination and inclination are 182.5° and -32.5° (k= 12.6; α95=11.6), respectively, corresponding to an average rotation of 2.3°±11.4° of the whole Mula Basin. Summarizing, the horizontal lineation parallel to the NW-SE oriented fold axis suggests an initial thrust tectonic deformation mechanism, and the local vertical-axis rotations suggest a subsequent predominantly strike-slip deformation. Our data show that the post-collisional crustal convergence in the Mula basin was accommodated by Cenozoic thrusting and strike-slip faulting inducing local crustal blocks rotation. Finally, our new paleomagnetic data show compatibility with a "quasi-continuous crustal flow" model, where small-scale crustal blocks are deformed by quasi-continuous crustal kinematics and does not match with the "quasi-rigid block" and the "mega-blocs tectonic escape" models.

**Keywords:** Tibet, Paleomagnetism, Block rotation, Strike-slip faults, Red beds

# Joint application of fluid inclusion and clumped isotope (Δ47) thermometry to burial carbonate cements from Upper Triassic reservoirs of the Paris Basin

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Tutors, co-tutors: Corrado Sveva[1], Gasparrini Marta[2,4], Bernasconi Stefano[5]

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A realistic reconstruction of the time-temperature history of sedimentary basins is critical to understand basin evolution and to predict oil maturation and migration as well to assess reservoir quality. Still, conventional geothermometers may be affected by important limitations (especially when applied to carbonate materials) and therefore the application of new methodologies is deserving attention in both academic and industrial research. Carbonate rocks undergo through mineralogical and petrophysical modifications during postdepositional diagenetic processes. Understanding the temperature at which those transformations occur and determining the geochemistry of the driving fluids is critical to constrain depth and timing of the depositional events and to understand paleo-fluids origins and their evolution through time. The study of diagenetic minerals, thus, plays an essential role in reconstructing accurate conceptual models allowing a correct assessment of basin and reservoir models which are critical for performing accurate simulations. Here, we put to the test the joint application of two independent thermochronological indicators: the more traditional fluid inclusion microthermometry (FIM) and the recent Clumped isotopes thermometer (Δ47) applied to carbonate burial cements (T>60°C) precipitated in a well-known geological succession, to better understand and constrain their own application limits. The aim of this study is to compare thermal information acquired by Δ47 thermometer and fluid inclusion microthermometry on diagenetic carbonates having precipitated at temperatures between 70°C and 115°C in Upper Triassic reservoirs (depths of 1820-2450 m) from the Paris Basin, having suffered 120°C during maximum burial. The data will also contribute to better reconstruct the thermal and geochemical conditions of past fluid-flows. A conventional diagenesis characterization study has been accomplished in samples from three different cores drilled in carbonate-cemented siliciclastic reservoir units of the Paris Basin (*Grés de Chaunoy* formation) and located in the northern part of the basin depocenter. A complete cement paragenesis was reconstructed highlighting three different burial cements: two non-ferroan blocky calcite phases (Cal1 and Cal2) and one non-ferroan dolomite phase of saddle type (Dol1). Fluid Inclusion microthermometry indicates homogenization temperatures spanning from 60°C to 95°C, mode of 67.5°C for Cal1; 70°C to 110°C, mode of 84°C for Cal2, and 100°C to 130°C, mode of 115°C for Dol1. Δ47 thermometer displays overall lower temperatures for calcite cements, indicating probable thermal re-equilibration of the fluid inclusions, and a fairly similar temperature for the saddle dolomite cement. Discrepancies between the obtained temperatures through conventional FIM and Δ47 thermometry, may lead to an erroneous assessment of the time of precipitation of the different diagenetic phases and, thus, to an erroneous thermal history and fluid-flow reconstruction. This work emphasizes the necessity of better understanding the limitations and applicability fields of these thermometric tools, especially when applied to diagenetic realm where thermal-induced mineralogical transformations are most likely to happen.

**Keywords**: carbonate diagenesis, Δ47 thermometry, fluid inclusion microthermometry, Paris Basin, Thermal history.

# Structural analysis of the Central Apennine-Central Adriatic Sea through 2D/3D modelling.

**D'Ambrosio Andrea[1]**

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The study area is located in Central Italy, including the Central Apennines fold-and-thrust belt front and its adjacent foredeep/foreland system. The off-shore sector, mostly undeformed Central Adriatic foreland, has been affected by extensional tectonics (from the Late Triassic – Early Jurassic to the Cretaceous time) and followed by the Apennine and Dinaric orogeny from the late Eocene, that finally guided the geological evolution of the area up to the current situation. On the contrary, the deep structural evolution of the Central Apennine is strongly debated in the literature, also due to the lack of an adequate public geophysical data. In addition, since the last century the area has been also an important target for the hydrocarbon exploration, with several oil&gas field discovered both on-shore and off-shore.

The public subsurface dataset produced by this activity (ViDEPI project) has been collected together whit the present regional geological maps (1: 50,000 & 1: 100,000; CARG project) and the geophysical data available in literature (e.g. seismic & tomographic sections and relocated earthquake hypocentres) in order to complete a 3D geological dataset.

The idea is to construct, using the basin modelling approach (PetroMod software) a solid 3D structural and geological model of the study area (focused on part of the Central Apennine-Central Adriatic Sea) in which all the Petroleum System knowledge of the region (oils geochemistry, geographic position of the main fields and the hypothetical source rock maturity) is considered as an additional model constraint.

Indeed, following the 1D/2D basin modelling approach of D'Ambrosio et al. 2020 (in progress) we will extend firstly in 2D and after in 3D the structural restoration work and Petroleum System modelling, in order to test our geological model from a structural, thermal and organic matter maturity point of view. The interpretation and the model building have been carried out using both the Petrel & MOVE software platforms, implementing all the geological information collected during the previous work phase, into a 3D seismic volume.

As results, we built a preliminary on-shore 3D structural model for the Central Apennine, based on the convergence of the entire geological and geophysical dataset previously collected (using the Qgis, MOVE and Petrel 3D software).

From a structural point of view, we defined the main regional structural and geological subsurface trends through the construction of several balanced 2D regional sections across the Central Apennine fold and thrust belts, characterised by an average of distance of 2-4 km between each section.

The dense network of geological sections constructed for the Gran Sasso-Morrone-Maiella mountains, allowed to calculate and extract the displacement values for the main compressive and normal faults system, that are summarized in a structural regional map.

Finally, starting from the resulting 3D geological model (from a simplified version) we will define a 3D velocity model implementing the interval velocity for the main stratigraphic sequences,

giving a contribution for the earthquake localization in a vulnerable area from the seismic hazard point of view (especially the on-shore sector).

**Keywords**: Central Apennine tectonic evolution, basin modelling, Petroleum System, structural restoration, faults displacement analysis.

# Cenozoic multiphase orogenic deformations in Northern Calabria Arc: hints from geological mapping in the Longobucco Basin

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The Meso/Cenozoic geodynamic evolution of the Calabria Peloritani Arc (CPA) has been, and is still, hotly debated, this sector of the Apennine chain being an exotic continental ribbon scraped off from its original position (European Plate) during the south-eastward migration of the Apenninic slab. The Southern sector of the Arc (Peloritani Mts.) has been analysed using a multidisciplinary approach. An analysis of pre-, syn- and late-orogenic siliciclastic deposits (Militello Fm, Frazzanò Flysh, Capo d'Orlando Fm) is essential for our understanding of how orogenic phases developed through the Late Cretaceous and Palaeogene. Biostratigraphical constraints reveal a multi-step compressive history, with discrete events (Alpine phase – Balearic phase – Apenninic phase)

The Northern sector of the Arc is conversely less well known, namely with regards to its pre-Serravallian history, due to the lack of continuous exposures of the Meso/Cenozoic sedimentary cover. One remarkable exception is the Longobucco Basin (Sila Greca, CS), where a Meso/Cenozoic succession covers unconformably the igneous and metamorphic Hercynian basement. A geological mapping project of the Longobucco Basin is proving instrumental in constraining the Cenozoic dynamics of this sector of the Arc. In particular, the Paludi Fm has been analysed. This is a multifaceted lithostratigraphic unit, made of conglomerates/breccias, reddish marls and arenaceous turbidites, whose composition testifies the dismantling of an orogen. This unit is in turn crosscut and deformed by north eastward verging thrusts dated as Burdigalian by Vignaroli and co-authors (2014), therefore it also apparently predates a younger tectonic phase (see the Frazzanò Flysch in Southern CPA for an analogy).

Despite the regional importance of this Unit, its age is highly debated in the literature, ranging from the Late Cretaceous to the Aquitanian, according to different Authors. In this light, a biostratigraphic study of this unit (nannoplancton, micro- and macroforaminifera), has been performed.

Field mapping has revealed a wealth of sedimentary structures ascribable to ductile and or/brittle-ductile deformation, typical of mass transport deposits (*i.e*. slumps, non-tectonic thrusts, pseudo sigma structures, asymmetric rootless folds and ductile shear zones). The occurrence of olistostromes, with evidence of syn-emplacement deformation, has been mapped. These plastically deformed bodies are Late Cretaceous in age (Aptian to Maastrichtian). They document lost parts of the succession, eroded during the uplift phases and cannibalized within a younger part of the succession, which must therefore be post-Cretaceous.

Being the age obtained from micropaleontological data comprised between the Eocene and the Oligocene, we must preliminarily ascribe the emplacement stage to an alpine phase. The Burdigalian thrusting event predates the opening of the Tyrrhenian sea and the detachment of the CPA from the Corsica-Sardinia block. It cannot therefore be ascribed to an Apenninic *s.s.* phase. We attribute this thrusting event to an earlier phase (Balearic phase) related to the Corsica-Sardinia block rotation.

Vignaroli G., Minelli L., Rossetti F., Balestrieri M.L. & Faccenna C. (2012) - *Tectonophysics*, *538*, 105-119.

**Keywords:** geological mapping, biostratigraphy, sedimentology, syn-orogenic deposits.

# Tempo and dynamics of the peri-Tyrrhenian Quaternary explosive volcanism inferred from distal archives

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Past explosive volcanism is commonly reconstructed using near-vent deposits, where the geological record provides fundamental information useful for evaluating eruptive and emplacement dynamics, and the evolution of the volcanic edifice. Due to the occurrence of coarse-grained K-rich crystals, proximal outcrops are also suitable for direct isotopic dating techniques, such as $^{40}Ar/^{39}Ar$. However, intense volcano-tectonic and sedimentary processes occurring close to a volcano cause proximal outcrops to be often fragmentary and incomplete and the eruptive history to be only partially represented and/or directly observable.

In contrast, distal archives can continuously record sedimentation of ash (tephra) layers, providing useful integrative information for a better reconstruction of the history and dynamics of explosive volcanic activity. During the Quaternary, large lake systems hosted in intermountain basins in central-southern Apennines (e.g. Fucino and Sulmona), recorded tephra deposition from the peri-Tyrrhenian and insular volcanic districts, including Vulsini, Vico, Sabatini, Colli Albani, Somma-Vesuvius, Phlegrean Volcanic District, Ischia, the Aeolian Islands and Mount Etna, which were characterised by an intense and recurrent explosive activity.

These basins have been almost continuously documenting the sedimentary history since the Late Pliocene-Early Pleistocene and are in a favourable position with respect to the prevailing eastward direction of the stratospheric winds and in a good range of distance (100 to 150 km) downwind of the peri-Tyrrhenian volcanic districts, thus being the perfect candidate to recover a long and continuous record. Among the Apennine intramountain basins, the Fucino and Sulmona ones were found to host a rich tephrostratigraphic record of the peri-Tyrrhenian explosive activity. However, the two lacustrine successions have been only partially studied and further stratigraphical, geochemical and geochronological analyses are required.

**Keywords**: Tephrostratigraphy, Quaternary, Explosive Volcanism, Central Italy, Distal Archives

# Reconstruction of the intensive variables and magmatic architecture of Vulcano island (Aeolian Arc, Italy)

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In this study, we present new mineralogical and petrological data on olivine, clinopyroxene, plagioclase and titanomagnetite phenocrysts from sixteen eruptive products (i.e., lava flows and pyroclastic deposits) collected at Vulcano island (Aeolian Arc, Italy) and representative of a relatively wide time period, from Epoch 5 (70-42 ka) to Epoch 8 (< 8 ka). These rocks show shoshonitic (SHO) to high-K calc-alkaline (HKCA) affinity, with compositions evolving from basalt (Mg#57-60) to basaltic trachyandesite (Mg#35-41) to trachyandesite (Mg#32-54) to trachyte (Mg#30-40) to rhyolite (Mg#23-28). The intensive variables driving the crystallization of magma were reconstructed by employing mineral-melt equilibrium and thermodynamic models, as well as barometers, thermometers, hygrometers and oxygen barometers. The stability of olivine (Fo58-71), as first phase on liquidus, is restricted to 100-300 MPa and 1040-1110 °C. Afterwards, the melt is co-saturated with clinopyroxene (Mg#92, diopside), which composition progressively evolves (Mg#71, augite) as the temperature decreases to 1070 °C. The jadeite exchange between clinopyroxene and melt indicates that the overall decompression path of magmas ranges from 900 to 0.1 MPa. The maximum crystallization pressure decreases from basalt/basaltic trachyandesite (900 MPa) to trachyandesite (650 MPa) to trachyte/rhyolite (250 MPa). The melt-water content (0.5-6.5 wt.%) is sensitive to either pressure or melt composition, thus controlling the plagioclase stability and chemistry (An13-77). Titanomagnetite (Usp11-29) equilibrates with progressively more evolved and oxidized melts, from ΔQFM+1.5 to ΔQFM+3. We conclude that the architecture of the plumbing system at Vulcano island is characterized by multiple reservoirs in which compositionally distinct magmas stall and undergo polybaric-polythermal differentiation, before eruption to the surface.

**Keywords**: petrology, volcanology, geothermobarometry, magma dynamics, plumbing system.

# Geological storage in fractured reservoirs of the Adriatic Basin

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In the field of the mitigation action to a low-carbon energetic system, the CCS (Carbon Capture and Storage) technology can give a great contribution, quantified around the 14% of the total emissions. This process consists in the capture, the compression and the transport of CO2, generated by the large power plants, and the injection in deep geological formations able to host it. Therefore, at the base of any CCS project there is the potential sites research and the calculation of the CO2 volume that can be hosted.

Fracture networks exist at a wide range of scale in the earth crust and strongly influence the hydraulic behaviour of rocks, providing either pathways or barriers for fluid flow. Many oil, gas, geothermal and water supply reservoirs form in fractured rocks, therefore are considered a great resource also in the field of storage. The main challenge is the development of numerical models that describe adequately the fracture networks and the constitutive equations governing the physical processes in fractured reservoir.

The hydraulic properties of fracture networks, derived from Discrete Fracture Network (DFN), models are commonly used to populate continuum equivalent models at reservoir scale, to reduce the computational cost and the numerical complexity. However, the efficiency of fracture networks to fluid flow is strongly tied to their connectivity and spatial distribution, that continuum models are not able to capture explicitly.

In this project through field data and synthetic models we want to introduce a new parameter to evaluate the efficiency of fracture networks to fluid flow, reflecting a range of variability in fracture network characteristics (e.g. P32, number of fractures, stress field). The simulation of fluid circulation will be then performed on the synthetic DFN models, measuring the behaviour of fracture network with respect to the total amount of injected / flowed gas through the model. This will allow to obtain different efficiency of several fracture networks for different values of fracture intensity and to apply it in the volume calculation for potential reservoirs with the same characteristics.

This alternative method allows to model fractured systems at reservoir scale, in a variety of geological settings, using exclusively a DFN approach.

**Keywords**: CO2 Storage; Adriatic Basin; Fractured reservoir; Discrete Fracture Networks; Fluid flow.

# Innovative procedures for the preventive conservation of library collections

**Elena Verticchio**

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Library collections are frequently affected by deterioration processes due to the environmental conditions in which they are stored. The conservation of paper is strongly interrelated with the air relative humidity, as organic-hygroscopic materials act as buffers on humidity fluctuations while being vulnerable to moisture-induced damage. Microclimate monitoring over long-term periods, in combination with whole-building hygrothermal dynamic simulation, provides a thorough characterisation of the indoor climate, thus becoming a compelling diagnostic and prognostic tool for the preventive conservation of cultural heritage. The hygroscopic behaviour of library collections can be modelled employing tools of the HAM-family (Heat, Air and Moisture), used to simulate the simultaneous 1-D heat and moisture transfers through porous envelope materials. The degradation scenario linked to the microclimate conditions experienced by collections can then be estimated either using dose-response functions for paper or performing measurements directly on the artifacts. In this project, the HMWall model is used for the first time to model the hygrothermal behaviour of paper collections as a single wall made in paper. The effect of the hygroscopic content on the indoor environmental conditions of library facilities is simulated coupling the HMWall model with the whole-building simulation software IDA ICE (Indoor Climate and Energy). Moreover, non-invasive spectroscopic techniques are used to investigate the material properties of the books that can be affected by the microclimate.

The aim of this research is contributing to the preventive conservation of paper collections through the development of innovative procedures based on an effective combination of microclimate assessment and refined hygrothermal modelling. To achieve this broad purpose, two specific objectives are pursued: 1) exploration of the capability of the software IDA ICE extended with the HMWall model in simulating the dynamics of heat and moisture exchanges within library storage facilities; 2) enhancement of the comprehension of the interactions between the microclimate and the books by means of spectroscopic techniques.

**Keywords**: cultural heritage, preventive conservation, hygrothermal modelling, whole-building dynamic simulation, paper collections

## CYCLE XXXIII part 1

# Crystal growth rate: experimental investigation at crustal-mantle boundary level in an alkaline basalt from the Campi Flegrei Volcanic District (South Italy)

**Barbara Bonechi**

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The kinetics of crystal nucleation and growth are fundamental for the interpretation of thermal history of a magma during its ascent to the surface and to constrain timescales of magmatic processes. In this experimental work, the effects of temperature, water content and time on crystals growth rate has been investigated in an alkaline basalt (APR16 sample) from Procida island, representative of the least evolved rocks of the whole Campi Flegrei Volcanic District (Italy). The starting material is an anhydrous glass prepared by melting the APR16 natural powder in a gas mixing furnace at 1400 °C and atmospheric pressure. Experiments were carried out at isobaric pressure (0.8 GPa) by using the piston cylinder apparatus at the HP-HT Laboratory of the Earth Sciences Department, Sapienza, University of Rome. A total of 24 experiments divided into three series were performed. Experiments of series 1 were carried out at anhydrous conditions, 1250 °C and 1200 °C and dwell time of 0.25, 3, 6 and 9 hours. Experiments of series 2 and 3, instead, were carried out at hydrous conditions (2 and 4 wt% H2O added to the starting material, respectively), 1220 °C and 1170 °C (series 2) and 1080 °C and 1030 °C (series 3), and the same dwell time of series 1. Clinopyroxene (cpx) is the dominant phase in the runs of series 1 and 2, while amphibole (amph) is the dominant phase in the runs of series 3. Cpx growth rate reaches a maximum value in the shortest experiments (~3·10-7 cm·s-1) decreasing to ~1·10-8 cm·s-1 in the longest duration runs. Similarly, amph growth rates range from 1.5·10-7 to 2.9·10-8 cm·s-1 with increasing the duration of the experiments. It is observed that, keeping a constant dwell time, an increase of the experimental temperature or of the water content results in comparable growth rate increase. Fe-Mg partition coefficients based on the crystal-liquid exchange show that mineral chemistry progressively approaches equilibrium with increasing run duration. Coexisting synthetic amph and cpx show a faster growth rates in favour of amphibole regardless of the dwell time. Moreover, the chemical composition of amphibole is influenced mainly by the experimental time; in detail, in the shortest (≤3 h) and low temperature runs edenite is the prevailing composition whereas the magnesiohastingsitic term becomes dominant at higher temperature and longer run duration. Finally, the determined cpx and amph growth rates were applied to natural scenarios. In particular, the combination of the cpx growth rates with data from thermobarometry and from crystal size distribution analyses of natural cpx in the most primitive scoria clasts of the CFVD, suggests that recharge by primitive magma in the deep reservoirs occurs with a relatively high ascent rate of ~0.5·10-4 m·s-1. Amph growth rates, instead, were used to constrain the crystallization time of natural amph and cpx from the Oligo-Miocene cumulates of north-western Sardinia (i.e., Capo Marargiu Volcanic District, Italy), yielding crystallization times in the range 1.46-3.12 yr.

**Keywords**: crystal growth rate; primitive alkaline basalt; high pressure; time-series experiments; Campi Flegrei

# Geostructural constrains to the gigantic Seymareh landslide (Zagros Mts., Iran) finalized to a landscape numerical modelling

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Tutors, co-tutors Marta Della Seta[1], Salvatore Martino[1], Reza Nozaem[2]

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The Seymareh rockslide-debris avalanche is the largest known subaerial non-volcanic landslide on Earth (44 Gm3), occurred ~10 ka in the Zagros Mountain Range along the NE flank of the Kabir Kuh fold (Iran). Because of the giant dimensions and the exceptional nature of the event, the landslide was studied by several Authors with different aims, among which identifying the triggering mechanisms. In this frame, our study is aimed at providing new insights on the geostructural and geomorphological factors for this kind of gravitational instability, starting from the reconstruction of the evolutionary and the geotechnical model of the Seymareh river valley before and after the exceptional event.

Geomorphic markers of the valley evolution have been identified after detailed geotechnical and geomorphological surveys and OSL dating of Quaternary deposits. River profile metrics showed the evidence of a transient landscape and the plano-altimetric distribution of the geomorphic markers has been correlated to the detectable knickpoints along the Seymareh river longitudinal profile. The analysis leaded to the identification of five different sectors of the NE flank of the Kabir Kuh fold, whose geostructural and geomorphological characters account for a different proneness to a massive rock slope failure such as the one occurred on the Seymareh landslide slope. Based on the reconstructions of the Seymareh river valley evolution and on an engineering-geological modelling of the outcropping succession of rock masses, the following geostructural and geomorphic factors have been identified as possible constraints for planned landscape and stress-strain numerical modelling: i) the stratigraphic setting, ii) the structural setting, iii) the relief conditions, iv) the kinematic releases, v) the time available for rock mass creeping. More in particular, the Landscape Evolution Model (LEM) of the Seymareh river valley before and after the emplacement of the landslide will be used as input as shape input for stress-strain numerical modelling under creep conditions of slope to calibrating the rock mass rheology by a back analysis and verify the possible role of seismic trigger for the Seymareh landslide as ultimate paroxysmal scenario following a rock mass creep process.

**Keywords**: Mass Rock Creep; Geomorphic Markers; OSL dating; Seymareh Landslide, Zagros Mountains.

# HydroQuakes: a pilot study in the central-southern Apennines for the realization of a hydrogeochemical monitoring network for seismic precursors and other societal applications

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The aim of this work is to provide a methodology for the investigation of seismic precursors starting from hydrogeological, hydrogeochemical, and seismic study of the territory. Hydrological effects originated during the seismic cycle (particularly prior to and during strong earthquakes) have long been observed and documented, as they are among the most outstanding coseismic phenomena that can be even observed over great distances. Moreover, since a few decades, geochemical changes of groundwater prior to intermediate and/or strong (Mw ≥ 5.0) earthquakes have started to be a concrete hope and, at the same time, a big scientific and technological challenge for geoscientists working in the field of seismic precursors. Deformation and stress perturbation during the seismic cycle can cause changes in deep fluid migration eventually leading to changes in shallower groundwater circulation and geochemistry. As monitoring sites, we identified the Sulmona and Matese areas in the central-southern Apennines. These two areas were affected in the past by Mw > 5.5 earthquakes. Each study area includes 5-6 monitored springs and boreholes. Groundwaters are mainly calcium-bicarbonate type or secondarily sulphate-calcium-bicarbonate type. Continuous monitoring and monthly sampling of the two study areas started in December 2017, although in the Sulmona area they had already started in 2014 for a previous project, whose results have been published in previous papers. In an attempt to identify potential seismic precursors, we carried out, for each monitored spring, analyses of major and trace elements and analyses of isotopes of the water molecule, boron, and strontium. During these years of monitoring (2018-2019), there were no high magnitude earthquakes. The three seismic events with the highest magnitude were indeed the 2019 Collelongo (Mw 4.1, January 1st), Balsorano (Mw 4.4, November 7th), and San Leucio del Sannio (Mw 3.9, December 16th) earthquakes. The most interesting result is that these earthquakes (except Collelongo) were not substantially preceded by hydrogeochemical anomalies. This evidence suggests that this type of pre-seismic anomalies could arise substantially only with intermediate and strong earthquakes (Mw≥5.0); however, it is also true that the Collelongo earthquake, which occurred on a very large Apennine normal fault (the fault that generated the great Avezzano earthquake of 1915, Mw 7.0) at great depths - about 16-17 km -, was preceded by very weak hydrogeochemical anomalies of Li, B, and Sr in most monitored springs. These weak anomalies could be related to pre-seismic breakages at great crustal depths along a very large fault. We also describe the monitoring stations as well as the used instrumentations, procedures, and analyses. We propose some preliminary results that emphasize the importance of collecting data from a widespread network of monitoring stations over a seismic territory and for long time. HydroQuakes provides new evidence for the importance of building a national hydrogeochemical network for the identification of seismic precursors. Future possible implementations as well as further societal uses for such a network are also addressed. The HydroQuakes Project is funded by Fondazione ANIA to CNR-IGAG.

# Holocene and historical morphodynamics of the Lower Mesopotamian waterscape: a remote sensing, multi-sensor approach

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During the Holocene the Tigris-Euphrates river system, at the lower sector of the Mesopotamian Plain (Iraq), has been characterized by a complex morphodynamics in response to climate fluctuations and the extensive construction of artificial canals, dug since the first River Valley Civilizations. During the early Holocene, the sea-level rise caused a general and rapid northward shifting of the Persian Gulf shoreline, after which the general progradation of the Tigris and Euphrates delta system accounted for the shoreline regression up to the present position. Several studies focused on the Mesopotamian waterscape to identify, among others: i) the position of the shoreline during the maximum Holocene marine ingression (i.e., 6,000 yr BP); ii) the effect of the Tigris and Euphrates paleo-delta progradation during mid and late Holocene; iii) key features useful for distinguishing natural river channels from anthropogenic canals. In this context, this study aims to enhance the knowledge on the Holocene and historical morphodynamics of the Lower Mesopotamian waterscape and, in particular, on the paleo-hydrology of the ancient fluvial system. In particular, this study provides new geomorphological data useful for better comprehending the mechanisms and rates of the complex interactions between the dynamics of the natural waterscape and the distribution, shifting and abandonment of historical settlements and artificial canals.

A remote sensing, multi-sensor approach has been adopted to identify the main geomorphological features and describe the associated morphogenetic processes. Optical and multi-spectral Landsat 8 satellite images have been processed for computing NDVI and Clay Index, as well as to extract Regions of Interest (ROIs). The spectral signatures of the ROIs have been extracted and compared among them. This analysis has been integrated with the investigation of the micro-topography obtained through the re-classification of different DEM sources: i) C-band interferometric SRTM (ground resolution of 30); ii) optical ALOS datasets (ground resolution 30 m).

Remote sensing multi-spectral analysis revealed useful to identify and delineate the geomorphological features associated to the Holocene progradation of the ancient Tigris and Euphrates delta system, past flood-events along the main distributary channels, surficial effects of channel migrations and marshes distribution. In particular, past flood-events have been identified by depositional and erosive landforms due to avulsion processes and the associated crevasse splays, other than by the position and planar pattern of artificial canals. In fact, these latter were essential for managing hydrological extreme events and, on the other hand, to take advantage from them (i.e. field irrigation system). Micro-topography analysis, integrated by the study of distribution of ancient settlements and the planar configuration of ancient distributary channels and artificial canals, allow to preliminary distinguish the geomorphological effects of the Holocene sea-level variations and the associated variations of the river morphodynamics.

Keywords: Hydrological Extreme Events (HEXs), remote sensing, multispectral analysis, geomorphological reconstruction, waterscapes

# Palaeoenvironmental analysis of a Phoenician site: Archaeobotany at Motya (Sicily, Italy)

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The presented research is framed within the context of plant use across the Mediterranean during the 2nd and 1st millennia BCE. More specifically, it aims to reconstruct plant cultivation and plant use of the Phoenicians at Motya, a small island (ca. 45 ha) found in the Marsala Lagoon, in Western Sicily (Italy), through the study of macro- (seeds and charcoal) and microfossils (pollen) and the support of archaeological evidence. Although the Phoenician-Punic period (late 8th century – 397 BCE) represents the main occupational phase of the archaeological settlement, the island is known to have been occupied by indigenous populations since the 17th century BCE and continued to be inhabited also after the Siege of Motya (397/6 BCE), despite not recovering its former importance. Despite of the "Missione Archaeologica a Mozia" being multidisciplinary, covering archaeological, anthropological and archaeological issues, no archaeobotanical study has been undertaken so far.

The sediment collected for the analysis of macro-remains was processed on-site using the bucket floatation technique. Once dry, the light and heavy fractions were processed in-lab using a series of piled up meshes and handpicked under a stereomicroscope. Carpological remains were later identified using the same microscope, whereas antracological remains were observed and identified using a Nomarski microscope. The analyses focus on two closed contexts referable to the Phoenicio-Punic occupation, giving an image of the sacred and the profane. The first context is comprised by a sacrificial pit found on the SW side of the temple of Cappiddazzu, where archaeobotanical remains are preserved mostly by mineralization and give insights regarding the use of plants in correspondence with ritual practices. The second is a disposal pit found in Area D where the materials, preserved mostly by charring, provide information regarding diet, agricultural practices and past herbaceous flora.

These analyses are complemented by the study of pollen from soil samples connected from the different excavation areas (partly carried out at the National and Kapodistrian University of Athens, Greece), in order to acquire an overall image of past flora. Preliminary analyses show high percentages of synanthropic taxa, such as Asteraceae and Brassicaceae.

**Keywords**: archaeobotany, Phoenicians, palynology, paleodiet, palaeoenvironment

# Acoustic response of bitumen-saturated carbonate rocks at increasing temperature from laboratory-scale study to model.

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Unconventional oils are emerging as an alternative hydrocarbon reserve since conventional oil is depleting nowadays. A kind of unconventional oil is bitumen, which is characterized by high density, high viscosity and API gravity less than 10° and these physical properties are temperature sensitive. Therefore, an accurate assessment of variation in the petrophysical properties of bitumen (HHC) and host rocks as a function of temperature is interesting in oil exploration industry.

In this work we investigated the temperature effects on laboratory seismic wave velocity of carbonatebearing rocks of the Majella reservoir that can be defined as a natural laboratory to characterize the carbonate reservoir properties. Moreover, we benefit of a set of samples that outcrops naturally in saturated and unsaturated conditions and thus, we can evaluate the influence of HHC on the carbonate matrix.

We conducted ultrasonic measurements (at the HPHT laboratory of INGV, Rome) of compressional and shear wave velocities on carbonate samples of the Bolognano formation, which show different HHC content and porosity between 10% and 19%. Wave velocities were measured in a range of temperature from 90 to 25°C at ambient pressure conditions. Firstly, we measured HHC density by HCl dissolution of the hosting rock, that resulted to be included between 1.14 and 1.26 gr/cm3 at ambient temperature. Then, we have calculated HHC content of our samples, spanning from 2% (low HHC-bearing sample) to 16% (high HHC-bearing sample). Our acoustic velocities point out an inverse relationship with the temperature. P- and S wave velocities depict a distinct trend with increasing temperature depending on the amount of HHC content. Indeed, samples with the highest HHC content show a larger gradient of velocity changes in the temperature range of about 60°-50°C, suggesting that bitumen can be in a fluid state. Conversely, below about 50° C the velocity gradient is lower because, at this temperature, bitumen can change its phase in a solid state.

Finally, we propose a theoretical model to predict the P-wave velocities, which seems to be more temperature sensitive than Vs, for different initial porosities, within investigated temperature range and with different HHC content.

In conclusion, our results highlight a strongly temperature dependence for bitumen-bearing carbonate properties and bitumen influences the acoustic response of carbonate rocks. Such petrophysical characterization would provide a better link between seismic parameters and the hydrocarbon properties with important implications for reservoir characterization from seismic data and for production monitoring.

**Keywords**: Carbonate reservoir, acoustic measurements, bitumen density, temperature effect, Pwave velocity model.

**CYCLE XXXII**

## Using radioisotopes in the assessment and dating of NAPL contaminations

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The management of unwilling leakages of oil refined products still represent a critical problem before and during remediation of a polluted site. Considering their immiscibility with water, these substances are defined as Non-Aqueous Phase Liquids (NAPLs). In soils NAPL distribution is regulated by their density that can create a plume located not only in the vadose zone but also in groundwater. Remediation procedures are often slightly effective on this kind of pollution and there are many difficulties in the allocation of the environmental recovery costs.

In this research the radioisotopes naturally present in the environment are considered as a tool to tracer a NAPL contamination and to assess its age. First, the accumulation in leaked NAPLs of 228Ra recoiled from 232Th contained in soil is studied to develop and propose a specific radiometric dating method (228Th/228Ra disequilibrium radioactive pair clock) by preliminary tests and dating tests on soil and water samples contaminated in laboratory and in situ. Secondly, Rn deficit technique is applied to monitoring an old contamination involving the shallow groundwater for a year.

Main results of this study include the development of a specific radiometric method based on environmental radioactivity due to alpha-recoil from 232Th and a more complete scientific understanding of the problems related to the contamination of a complex natural system. The comparison between different features of a real multiphase system can positively improve the management of polluted site in the near future and offer a solution to legal disputes by a new method for nuclear forensic.

**Keywords:** Environmental radioactivity, NAPL spills, dating method, alpha-recoil

# Mush cannibalism and disruption recorded by clinopyroxene phenocrysts at Stromboli volcano: new insights from recent 2003-2017 activity

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The Present-day (<1.2 kyr) activity of Stromboli (Aeolian Islands, Southern Italy) is fed by a vertically-extended mush column with an open-conduit configuration. The eruptive products are the result of periodic supply of mafic magma (low porphyritic or lp-magma) from depth into a homogeneous shallow reservoir (highly porphyritic or hp-magma). Clinopyroxene phenocrysts from the 2003-2017 activity exhibit marked diopside-augite heterogeneities caused by continuous lp-hp magma mixing and antecryst recycling. Diopsidic bands record lp-recharges injected into the shallow hp-reservoir, whereas resorbed diopsidic cores testify to the continuous disruption and cannibalism of relic antecrysts from the mush. The transition between diopside (~1,175 °C) and augite (~1,130 °C) takes place at comparable P (~190 MPa) and H2O (0.5-2.4 wt.%) conditions. Shorter timescales (~1 year) for diopsidic bands from the 2003 paroxysm document restricted temporal intervals between mafic injection, magma mixing and homogenization in the hp-reservoir. Longer timescales (~4-182 years) for diopsidic cores indicate increasingly antecryst remobilization times. By comparing clinopyroxenes from the Present-day and Post-Pizzo eruptions, we argue a distinct phase in the life of Stromboli volcano commenced at least after the 2003 paroxysm. More efficient mechanisms of mush disruption and cannibalism involve diopsidic antecrysts remobilized and transported by lp-magmas permeating the mush, in concert with gravitational instability of the solidification front and melt migration within the shallow hp-reservoir. Magmatic injections feeding the persistent Present-day activity are more intensively mixed and homogenized prior to eruption, reflecting small recharge volumes and/or a more mafic system in which the mafic inputs are less evident.

**Keywords**: Stromboli; clinopyroxene zoning; crystal mush; shoshonitic basalt; magma dynamics; P-T-H2O modeling; Fe-Mg diffusion chronometry.

## Recent volcano-tectonic evolution of the western Galápagos

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Western Galápagos calderas experienced repeated eruptive and non-eruptive unrest in the last decades, only partially studied. Here we investigated, using the Synthetic Aperture Radar Interferometry (InSAR) and geodetic modelling, the eruptive and the non-eruptive unrest episodes occurred in two of the less studied calderas of the western Galápagos: Alcedo and Cerro Azul. Alcedo underwent repeated non-eruptive unrest from 2007 to 2011, while Cerro Azul experienced an unrest, from 2007 to 2008, culminated in two eruptive phases from May 29$^{th}$ to June 11$^{th}$ 2008. Results highlight how Alcedo experienced two episodes of uplift due to new magma injections in its shallow magma reservoir, separated by an episode with a limited lateral propagation of magma, probably interrupted for the lack of new magma supply in the magma reservoir. Results also hint to a possible relationship between these short-term unrest episodes and the longer-term process of resurgence at Alcedo. As for Cerro Azul, we overcame unwrapping errors affecting some of the InSAR data of Cerro Azul by proposing a new method, based on the wrapped phase differences among nearby pixels, to invert the wrapped phase directly. Our results highlight how the eruption was preceded by long-term pre-eruptive inflation (October 2007 – April 2008). During the first eruptive phase, most of the magma responsible for the inflation fed the lateral propagation of a radial dike, which caused a first deflation of the magmatic reservoir. During the second eruptive phase, the further lateral propagation of the dike fed a radial eruptive fissure at the base of the edifice, causing further deflation of the magmatic reservoir. From the first to the second eruptive phase, the radial dike changed its strike propagating towards a topographic low between Cerro Azul and Sierra Negra. An increase in magma supply from the reservoir to the dike promoted the further lateral propagation of the dike, confirming the importance of a continuous supply of magma in the propagation of a dike.

# Factors controlling fracture distribution within a carbonate-hosted relay ramp: insights from the Tre Monti fault (Central Apennines)

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Fractures constitute the main pathway for fluids in fault damage zones hosted in low-porosity rocks. Understanding the factors controlling fracture distribution is hence fundamental to better assess fluids circulation in fault damage zones, with evident implications for fault mechanics, hydrogeology and hydrocarbon exploration. Being usually characterized by a strong damage and structural complexity, this is of particularly importance for relay zones.

We integrated classical and modern structural geology techniques to investigate the factors controlling fracture distribution within a portion of a relay ramp damage zone pertaining to the Tre Monti fault (Central Italy). The damage zone is hosted within peritidal carbonates and located at the footwall of the relay ramp front segment. We analysed the distribution of the fracture density in the outcrop through (1) scanlines measured in the field, (2) oriented rock samples, and (3) scan-areas performed on a virtual outcrop model obtained by aerial structure-from-motion.

Our results highlight structural and lithological control on fracture distribution. Scanlines and virtual scan-areas show that fracture density increases with the distance from the front segment of the relay ramp. Moreover, all the methods highlight that supratidal and intertidal carbonate facies exhibit higher fracture density than subtidal limestones.

This apparently anomalous trend of fracture density, that increases moving away from a main fault segment, has two main explanations. (1) The damage is associated with the relay ramp development: approaching the centre of the relay ramp (i.e., moving away from the front segment) an increase in the number of subsidiary faults with their associated damage zones promotes high fracture densities. (2) The increase in fracture density can be attributed to the increasing content in supratidal and intertidal carbonate facies that are more abundant in the centre of the relay ramp.

Our results provide important suggestions for factors controlling fracture distribution and fluid flow within relay ramps hosted by shallow water limestones. We show that the trend of fracture distribution with respect to a main fault is not easily predictable in presence of a relay ramp, because it can be modulated by the subsidiary faults formation and slip during the relay ramp development. Moreover, carbonate facies play a non-negligible role in fracture distribution within fault zones hosted in shallow-water carbonates.

**Keywords:** fractures; relay ramp; virtual outcrop; FracPaQ; Tre Monti fault

# Quaternary spatio-temporal uplift variations at the Central Anatolian Plateau (CAP) southern margin

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The southern margin of the Central Anatolian Plateau (CAP) records a strong uplift phase after the early Middle Pleistocene. During the last 450kyr the area underwent an uplift phase with mean rates between ~3.2 m/kyr, as suggested by the Middle Pleistocene marine sediments exposed at ~1500 meters above sea level. These values are significantly higher than those obtained for the Late Pleistocene/Holocene at the southern Anatolian coastal area (1.0 – 1.5 m/kyr) and suggest substantial variations of uplift rates through time. In geodynamically active areas, spatio-temporal variations in uplift are directly related to the evolution of topography. Marine and fluvial landscape features are strictly connected to the uplift and allow us to infer elements that reflect uplift variations in time and space. In the study case of the CAP southern margin we investigate the evolution of marine terraces and the drainage system through time by quantitative analysis and numerical modeling, simulating the development of marine terraces by a LEM (Landscape Evolution Model) and performing the linear inversion of the drainage system that bound the CAP southern margin, in order to define the Quaternary uplift trend. Our results are in accordance with the previous biostratigraphic estimation of the uplift and reveal an exponential increase and decreases in uplift rates during the last 500kyr, revealing also a west-to-east propagation in the onset of uplift pulse, that reach the higher magnitude in the western side of the southern plateau margin (~4,5 m/kyr at 400ky) and decrease in intensity and time moving to the eastern side (~3,5 m/kyr at 200ky).

**Keywords**: Anatolian plateau, uplift, marine terraces, drainage system, numerical modeling

# Object-oriented geomorphological mapping model for landslide systems analysis.

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Spatio-temporal relations between landslide occurrences are a key concept for landslides hazard evaluation. A symbol-based 2D mapping approach usually cannot store such complexity, especially in areas where the events succession is characterized by the superimposition of different landslide types, probably related to several triggering factors, therefore different recurrence time. The proposed object-oriented mapping approach allow to maintain the spatial integrity of the dataset, not only in the 2D space but also in the 3D space preserving vertical relations between overlapping objects or object components, an extremely common occurrence dealing with landslides, which is crucial for the correct implementation of topological models such as the Dimensionally Extended nine-Intersection Model (DE-9IM) and the Region Connection Calculus (RCC8). Treating landslides as objects lead to the introduction of landslide hierarchies. In this work the focal classes are populated with **landslide objects**, specialized by types, which result from the aggregation of their **component objects**, such as detachment areas, main bodies or debris and so on. Further generalization or aggregation of the focal classes objects produces two orders of super-classes: i) **landslide complexes**, specialized by type, containing all the landslide objects of the same class with at least a *partially overlapping* topological relation, assumed as "functional interaction"; ii) **landslide systems**, defined as the aggregation of interacting landslide complex objects and landslide objects. In this framework every object is related to a specific event, meaning that its structure is designed for the implementation of temporal data, both absolute (when available) and relative. Temporal analysis allows the transition from an object-oriented to an event-based mapping approach in a 4D time-space framework.

**Keywords**: landslide, object-oriented, landslide complex, landslide system

# The transport, sedimentation and deposition of the 39.8-ka Campanian Ignimbrite: a study from the field to the volcanic process

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Despite the large number of studies, the transport and deposition of pyroclastic density currents (PDCs) have remained a most debated issue in volcanology. Some explosive eruptions withdraw magma volumes of several hundred cubic kilometers, generate very large PDCs and the deposits can extend more than 100 km from their vent. Fundamental questions concern about the long run-out distances and what the propagation flow mechanism and the physics are behind these very large PDCs. One of these large-volume PDCs is the Campanian Ignimbrite (CI), the case study of this work, related to a caldera-forming eruption that occurred 39.8 ka in Campi Flegrei. The CI is widespread over an area of 7,000 $km^2$, with a final runout of about 80 km and deposits can be found at an elevation of around 1,000 m above sea level. In spite of the large number of studies, some questions are still open. The Dense Rock Equivalent (DRE) volume estimates range from 60 to 300 $km^3$. This work presents a new appraisal of the volume constrained by an isopach map that reconstructs the paleo-topography during the eruption. The total final volume estimate of the eruption ranges from 415.0 $km^3$ to 615.1 $km^3$ (164.9 $km^3$ – 247.7 $km^3$ DRE). This value corresponds to a mass of 4.30 - 6.46 x $10^{14}$ kg, a magnitude of 7.7 and a VEI of 7. The thickness data were used to analyze the PDC interaction with the paleo-topography, using the topological aspect ratio (ARt). A great effect of blocking is evident in front of topographic barriers, while a strong channeling occurred in the paleovalleys. Three different systems were recognized: the transport system, the sedimentation system and the depositional system. The transport system was extremely diluted and an index of a high energy flow, which developed the sedimentation system as the flow reached the topographic barriers. Depositional features, including valley-pond deposits with flat tops, the lack of veneer facies and of deposits at steep slopes suggest a near Newtonian behavior of the fluidized granular undercurrents of fine ash particles downhill generated by the sedimentation system. The undercurrents have clear evidences of a subcritical flow, thick and relatively slow. Both the indexes of high and low energy current (as sub and super-critical flow) suggests that CI can be considered as a new end member of ignimbrites.

**Keywords**: pyroclastic density currents, ignimbrites, ignimbrites volume, isopach map, Campanian Ignimbrite.

## CYCLE XXXIII part 2

# The Numidian Sand Event in the Western Rif Chain (Northern Morocco)

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We report on new sedimentological and biostratigraphical data concerning the "Numidian sandstones" outcropping in the Western Rif Belt. The analyzed sections are located south of Tangier city, close to the 9th April dam and pertain to the Intrarif Sub-domain, which, in turn, is part of the External Rif domain.

In the western peri-Mediterranean chains, the "Numidian sandstones" display constant lithological features. We analysed five well-exposed lithostratigraphic sections, which are organized in three portions: (1) the "sub-Numidian", mainly dominated by varicoloured clays, (2) the "Numidian sandstones", which includes predominantly massive quartzarenitic sandstones, sometimes interbedded with mudstones, and, finally, (3) the "supra-Numidian", characterized by alternation of light green marls and thin-bedded siltstones.

Stratigraphic sections of the "Numidian sandstones" were measured and described to provide detailed sedimentological characterization and facies analysis. The "sub-Numidian", thick more than 100 meters, is commonly made of varicoloured clays, which in all the studied sections shows a horizon rich in Tubotomaculum. In the study area, the "Numidian sandstones" are about 1100 m thick; their facies analysis have been performed. The basal part of the examined sections shows similar characteristics: proximal channels filled by very thickbedded disorganised pebbly sandstones and amalgamated structureless sandstones. The base of the beds is scoured and sometimes shows decimetresized mud clasts torn away from the substratum. Paleocurrents measurements, mainly indicated by flute casts, are from southeast to northwest. Upward, coarse-grained quartzarenitic sandstones mainly characterize the middle part of all the sections. They are organized in massive and thick-bedded pebbly-sandstones, micro-conglomerates, and disorganised thick sandstones strata, often marked by fluid escape structures, revealing flows processes controlled by high-density turbidity currents and debris flows. These deposits evolve to plurimeter- to decimetre-thick medium grained sandstone and mud couplets with a mainly fining-and thinning-upward trend. Commonly, the uppermost part of the sections shows a restoration of disorganised pebbly sandstones facies. The "supra-Numidian" caps the thick "Numidian sandstones" and is made up by about 60 m of bioturbated marls rich in planktonic foraminifera and fine-grained silty/muddy deposits. These latter show sedimentary structures related to unidirectional flows, probably owed to deep contourites currents.

**Keywords**: "Numidian Sandstones", Biostratigraphy, Sedimentology, Western Rif Chain, Morocco

# Acoustic T-phases recorded by seafloor observatories at the Tyrrhenian and Ionian deep sites

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In recent years, seafloor observatories were deployed in two sites of the Mediterranean area where important geophysical processes that have geohazard impact take place: offshore Eastern Sicily (Italy) in the Ionian Sea at 2100 m water depth and at the base of Marsili Seamount in the Tyrrhenian Sea at 3320 m water depth. The Ionian site, near Etna volcano, where the SN1 seafloor Observatory is deployed is a key point of the EMSO (European Multidisciplinary Seafloor and water-column Observatory Research Infrastructure, www.emsoeu.org). The second site, where the GEOSTAR seafloor Observatory was deployed during the ORION experiment, is the location of Europe's largest submarine volcano. In the present work we focus on seismically generated acoustic waves, called T-phases, that propagate within the ocean's low-velocity waveguide known as the SOund Fixing And Ranging or SOFAR channel. T-phases can propagate over great distances (thousands of kilometers) with little loss in signal strength. The study of T-phases are interesting to scientist for a number of reasons, one of them is that they might give information on the structure of subduction zones. T-phases were first studied on signals recorded at coastal seismic stations but thanks to the increased deployments of Ocean Bottom Seismometers worldwide, they also have been observed at the seafloor at depths greater than the SOFAR channel. The two seafloor observatories recorded high quality 3-component time series of acoustic signals that we identify with T-phases generated at nearby subduction zones. Thanks to accurate time reference of the data and knowledge of component direction for the seismometers on-board seafloor observatories it is possible to extract significant features on the T-phase signal. In particular, we show the efficient T-phase generation from earthquakes along the Hellenic and Calabrian subduction zones by computing of the maximum amplitude of the envelope of the T-phase $e_{max}(t)$ and the T-phase energy flux (TPEF) as function of the local Magnitude. Following, we performed a polarization analysis, on the three seismic components to investigate on possible factors that affect the T-phase energy loss along the propagation paths from epicenters to seafloor receiver.

**Keywords:** T-phase, acoustic propagation, Ionian and Tyrrhenian basins, seafloor observatories, EMSO ERIC Research infrastructure

# The post-orogenic deposits of the Simbruini-Ernici range in the framework of the Plio-Quaternary evolution of the Central Apennines

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The Simbruini-Ernici range is one of the main morphotectonic structures of the Central Apennines. This sector, in contrast with other Central Apennines sectors, lacks well defined intermountain basins and the post-orogenic history is recorded only by several sedimentary cycles of continental detrital deposits, mainly carbonate in composition, undated up to now.

Several deposits located in different tectonic domain, from the internal to the external range area, have been analysed: Vallepietra and Filettino deposits are located in the Simbruini range axial zone, at the hanging wall of an important and complex tectonic lineament called the "Vallepietra - Filettino Line" which brought the cretaceous limestone, Miocene and messinian facies, above in tectonical contact which the Jurassic-Triassic sediments. While Guarcino, Vico nel Lazio, Collepardo and Santa Maria Amaseno deposits are located along the external margin of the Ernici range, at the footwall of the Guarcino-Trisulti fault system.

Thanks to a multidisciplinary approach that includes a detailed geological and geomorphological survey and the paleomagnetic analysis, it was possible to define and classify the different detrital deposits based on their lithological, magnetic and petrographic features. Because of the nature of the continental barren deposits, observations under cathodoluminescence were performed to possibly identify different cement generations based on their luminescence. This was done aiming to sample promising samples for O-C isotope analyses as well as U-Pb radiometric analysis.

Most interesting deposits are the Faito and Collepardo one. On top of Faito plateau several meters of detrital carbonate continental deposits outcrop between 1200 and 1600 m asl., the deposit shows an evolution from a slope to a conoidal environment. To the south east, deposits similar to the Faito, outcrops also in Collepardo area. Thanks to the interpolation of paleontology and magnetic polarity data, Collepardo normal conoid has been associated to the chrono Gauss in upper Pliocene. Considering that Faito deposits are located at higher altitude, are disconnected from the source of clast composition and are deeply faulted and carsified, we assume that the reverse Faito deposits could been associated to the chrono Gilbert in lower Pliocene.

The analysed detrital deposits are due to the morphogenesis associated with the phases of lifting and dismantling of the central Apennine orogen and they have been preliminary associated to a respective chrono, from Pliocene to Pleistocene.

**Keywords:** Central Apennines, continental deposits, paleomagnetis, morphotectonic, depositional processes

# Experimental study on the rheology of bubble-bearing magmas

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Volcanic activity consists of a wide range of eruptive styles, which are controlled by the gas phase within magmas. The comprehension of the rheological behaviour of these mixtures of melt, crystals and bubbles is primary to understand the physical mechanisms within the volcanic systems. To date, scientific community tried mostly to understand the rheological behaviour of crystal-bearing magmas, due to a minor complexity in performing experiments. Difficulties in the investigation of the bubble-bearing magmas are due to the outgassing of the gas phase from the samples during the experiments. So, while the influence of crystals in magma rheology is better understood, a model for the comprehension of the rheology of the bubble-bearing magmas appears far from being available.

The aim of this work is to understand the complex dependence of the viscosity on vesicles and strain rates, by performing suites of in situ degassing experiments of cylindrical rhyolitic samples at an experimental temperature of 850 °C, followed by uniaxial deformational experiments (constant strain rates of 5*10-5, 10-4 and 10-3 s-1) through the Volcanology Deformation Rig (Quane et al., 2004) at chosen experimental temperatures (720-800 °C).

Preliminary results show a complex pattern due to the initial increase of relative viscosity for low amounts of vesicles (0-20%). For higher vesicularities, a non-linear trend of viscosity under the same porosity at different strain rates can be identified: viscosity reaches a peak for a strain rate of 10-4 s-1. The general trend shows that, above the 20% threshold porosity, at constant strain rate, the viscosity decreases. There is therefore a complex dependence of the rheological response as a function of the strain rate.

Further investigations will focus on the definition of the rheological behaviour of magmas at a wider range of strain rate, trying to characterize the trend of the viscosity within the ductile regime of deformation.

# The HT diffusion of hydrogen in riebeckite

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In this work we address the diffusion of hydrogen at high temperature in a sample of riebeckite close to the end-member composition $Na_2Fe^{3+}{}_2\ Fe^{2+}{}_3Si_8O_{22}(OH)_2$. We carried out isothermal experiments on both powders and single-crystals and monitored the behavior of the O-H stretching signal by FTIR spectroscopy. Two different sets of experiments were performed: in the first one we collected data on five doubly-polished chips with the same thickness (85 μm) at different temperatures, in the range 520 to 560 °C. For the second set, we collected OH-stretching data at a constant T = 550 °C on six samples with thickness ranging between30 and 150 μm. In any case the target temperature was reached as fast as possible (90°C/min rate) and held constant while collecting FTIR spectra every 2 minutes, until the complete disappearance of the OH-signal. Preliminary spectra collected on amphibole powder embedded in KBr disks showed no OH loss even after prolonged heating, therefore the isothermal experiments were performed on pellets consisting of compressed pure powder. The integrated OH intensities as a function of time were fitted using the Avrami equation; for single-crystals, the data showed an initial intensity increase that was fitted testing two different procedures. The resulting parameters were plotted in the Arrhenius space to derive the activation energy ($E_a$) for the $H^+$ diffusion in riebeckite. The final values are: 19.6±1.5 kJ/mol (from powder data), 26±3 kJ/mol or and 34±2 (from single-crystal data, depending on the fitting method). The activation energy for powders is lower than that obtained for single-crystals, and this result supports the model in which the oxidation of amphiboles occurs at the sample surface. Moreover, the $E_a$ obtained here are considerably lower than the values reported in the literature (e.g. Ingrin and Blanchard, 2006) for pure diffusive processes of $H_2$ and $H_2O$ through several different crystal matrixes. It is also consistently lower that all values reported so far for amphiboles (e.g. Johnson and Fegley, 2003). This can be related to the peculiar deprotonation mechanism in riebeckite where the OH - $O^{2+}$ substitution at the anionic O3 site is coupled to $^{M(1)}Fe^{2+}$ - $^{M(1)}Fe^{3+}$ oxidation (e.g. Della Ventura et al., 2018, Galdenzi et al., 2018) and the transformation of the phase into an oxi-amphibole.

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# An improved seismic model of the upper mantle below the Tyrrhenian Sea: implications for current thermo-chemical conditions and geodynamical evolution

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The Mediterranean Sea is the result of complicated interactions between different tectonic processes, most still going on, and therefore is a natural laboratory for understanding the geological and geodynamical processes on a global scale. Although this area has been extensively studied for many decades, the deep crust and the upper mantle beneath the Central Mediterranean Sea, and in particular the Tyrrhenian Sea, remain relatively unexplored from a seismological point of view. This research project aims to model the current thermo-chemical conditions of the upper mantle beneath the Tyrrhenian Sea at an unprecedented resolution in order to shed light on the geodynamical evolution of this back-arc basin.

For doing this, we rely on all available seismic waveforms from the *FDSN Web Service* of many European providers and on the in-house seismic data of the LiSard (Lithosphere of Sardinia) project, that consists of 11 broadband seismic stations, and that provides a better seismic coverage of the area in comparison to previous studies. We already computated dispersion curves of surface waves from ambient noise (AN) and earthquakes (EQ). By performing a joint inversion of Rayleigh and Love phase velocities we obtained the 3-D shear-velocity structure of the study area, down to depths > 150 km. In addition, we are investigating the radial anisotropic structure of the crust and uppermost mantle of the same area by means of a non-linear Probabilistic Montecarlo Markov Chain inversion, using the AN dataset only.

The final part of the project, yet to be worked out, will involve the interpretation of the models in the broad context of the evolution of the Mediterranean. Our results will provide an insight into the rheology of the Tyrrhenian Sea and other portions of the Mediterranean. Effects of fluids and melt onseismic velocity and anisotropy will be also used for the interpretation.

**Keywords**: Seismology, Geodynamics, Surface waves and free oscillations, Seismic interferometry, Mineral physics

# Pressure-Temperature-time-deformation (*P-T-t*-d) history of the Alpine Upper Sebtides in the internal zone of the Rif belt (Northern Morocco)

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The Betic-Rif arcuate belt forms the western edge of the peri-Mediterranean Alpine orogenic system. The core of this orogenic domain, the Alborán Domain, is presently dismembered into discontinuous outcrops located in the internal domains, where post-orogenic Neogene extensional tectonics overprinted the early crustal thickening event. While the large-scale structure of this orogen is well known, the precise timing, the structural evolution, and the exhumation of the metamorphic units in the Alborán Domain are still unsolved and object of a long lasting debate.

With the aim to constrain the *P-T-t*-deformation history of the syn- and post-orogenic assembly in the Moroccan Rif, this study focuses on the Alpine subduction-related Upper Sebtides units and the contact between these units and the Barrovian Lower Sebtides (Filali units). This contribution deals with the first results relative to the tectono-metamorphic evolution of the low-grade Tizgarine unit and the HP/LT Beni Mzala units, the upper and lower structural levels of the Alpine metamorphic nappe stack in the Moroccan Rif, respectively.

In the Tizgarine unit, the main metamorphic fabric is developed during an early D1 top-to-the-SW shearing, guiding the ductile-to-brittle overthrusting onto the Dorsale Calcaire. The M1 mineral assemblage consists of Chl-Ms-Prl-Qz ± Cc. In the Beni Mzala unit a second-phase D2 S-L fabric is evident that postdates the HP foliation made of Car/Ctd-bearing assemblages. D2 deformation is partitioned between flattening domains and top-to-the-N non-coaxial ductile shearing, syn-kynematic relative to greenschist retrogressive metamorphism. The M2 assemblage consists of Qz-Chl-Ms ± Ep ± And. Significant is the presence of transposed HP Qz-Ky-Ms boudins. These boudins host highly substituted phengite muscovite ($Si^{4+}$: 3.2 a.p.f.u) in textural equilibrium with Ky that are the target of in situ Ar-Ar dating. Similar top-to-the-N ductile shearing is also reported from the topmost levels of the Filali miscaschists, where syn-to-post-kinematic Qz-Bt-Ms-And assemblages are observed.

The geochronological studies (Ar-Ar and U-(Th)-Pb methods) will be carried out in order to constrain: (i) the Alpine orogenic construction in space and time; (ii) the nature and age of the tectonic coupling between the Upper and Lower Sebtides; and (iii) the transition from orogenic construction to collapse in the region.

**Keywords**: Structural geology, Alpine orogeny, Upper Sebtides, Rif belt, Morocco

# Erosional response of granular material in landscape models

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Tectonics and erosion/sedimentation are the main processes responsible for shaping the earth surface. The link between these processes has strong influence on the evolution of landscapes. Despite the growth of different analysis techniques, our understanding of this interaction is still poorly defined and limited by the impossibility to observe these processes in their entire evolution in nature. Here we contribute to improve this understanding by six laboratory-scaled analogue models of erosion, later applied in a coupled system where both tectonics and erosion are considered. We explore the erosional response of different materials to the imposed boundary conditions, trying to find the sample (composite or pure) that best mimic the behavior of the natural prototype. The models recreate conditions in which tectonics is no more active, with an imposed fixed slope. On this slope the erosion is induced by precipitation, with the formation of channels in valleys and diffusion on hillslope that are function of the used analogue material. Using Digital Elevation Models (DEM) and laser-scan correlation technique, we show model evolution and measure mass discharge rates. We define how some materials already known in literature (e.g. silica powder) are fundamental for reproducing geomorphic markers that can be compared with natural prototypes. We also show that mixing these materials with others produce a different response. We propose three main components of our analogue material (silica powder, glass microbeads and PVC powder) according with latest works on the same topic, and we investigate how different proportions of these components affect the model evolution and the development of landscapes.

**Keywords**: tectonic geomorphology, river dynamics, analogue modelling, granular materials, erosion rate

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