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Cover Eruptive plume from Mount Etna the night of February 23rd, 2021 | *In copertina Plume durante l'eruzione dell'Etna nella notte del 23 febbraio 2021* ©Marco Restivo and Giuseppe Di Stefano - Etna Walk

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INVITED KEY LECTURE

Scientific improvements to reduce the hazard during volcanic eruptions: an example from Mt. Etna, in Italy

Simona Scollo

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etneo, Catania, Italy

Volcanic eruptions show a wide range of hazardous phenomena that can span from lava and pyroclastic flows to volcanic ash and gas emissions. Those events can create several diseases to population living near active volcanoes and impact very large areas. In order to mitigate volcano risks, a synergistic combination of observations of volcanic activity in real time with numerical models is needed. Real-time observations can be carried out using several remote sensing sensors as visible and thermal cameras, lidars, radars and satellite measurements, allowing to follow the evolution of the eruptive phenomena. Near real time forecasting is instead possible using different data assimilation techniques or improving the eruptive source parameter estimation through remote sensing sensors or/and geophysical data.
Mt. Etna, in Italy, is one of the most active volcanoes in the world. The recent explosive activity spans from violent strombolian to subplinian and occurs from the summit craters and fissures opened on the volcano flanks. During the last ten years Etna was very active, producing several lava fountain events which formed lava flows and high eruptive columns rising up to several kilometres above sea level. The copious tephra fallout mainly affected the northeast and east volcano flanks. Crops were damaged, houses suffered structural damages and transport operations were heavily affected. The ash cloud sometimes contaminated the controlled airspace of Catania and Reggio Calabria airports and tephra fallout disrupted their operations. Here we show that combining data from different remote sensing systems, many of them available at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo (INGV-OE), and numerical models, a more reliable evaluation of the eruptive phenomena and of the associate hazard can be achieved. Some examples applied to the recent volcanic activity are also shown.

INVITED KEY LECTURE

SESSION 1 - MAGMAS AND FEEDING SYSTEMS

Conveners:
Marisa Giuffrida and Giuseppe Re

Zoned clinopyroxene crystals as tracers of magmatic components involved in mixing/mingling processes occurred in the plumbing system of Zaro (Ischia island, Italy)

Carlo Pelullo[1,2*], Ilenia Arienzo[2], Sumit Chakraborty[3], Massimo D'Antonio[1], Ralf Dohmen[3], Manuela Nazzari[4], Lucia Pappalardo[2], Paola Petrosino[1]

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Analysis of textures and chemical zoning in minerals (mineral microanalysis) is one of the most efficient tools aiming at the investigation of plumbing system dynamics. Minerals, e.g. clinopyroxenes, can be highly sensitive to gradual or sudden changes in the volcanic system, and, for this reason, they are employed as archives of magmatic processes. Since cpx respond texturally and compositionally to changing magmatic environments, they preserve in their crystal "growth stratigraphy" a wealth of information regarding their past history of magmatic processes and compositions. Mineral microanalysis on zoned crystals aiming at investigating chemical and physical changes of the Phlegrean Volcanic District magmas is still poorly employed. Detailed mineral compositions have been obtained along transects of length varying from 20 µm to 800 µm on zoned clinopyroxene crystals of selected eruptive products belonging to the Zaro lava complex (<7 ka; Ischia island, South Italy). The main Zaro lava body is trachyte and hosts abundant mafic to felsic enclaves, whose textural, chemical and isotopic characteristics suggest mixing/mingling processes occurred before eruption. A selection of zoned cpx crystals from both host lava and enclaves was thus analyzed by acquiring major and minor elements (Si, Ti, Al, Fe, Mg, Mn, Ca, Na, K, Ni and Cr) along core-to-rim or rim-to-rim transects crosscutting the centers of crystals. The zoning pattern of the Zaro cpx consists of two or more plateaus with a constant composition separated by either sharp or gradual boundaries. Most of crystals are characterized by simple to complex reverse zoning. Different populations can be recognized within the compositional range of the Zaro cpxs, with significant differences among cpx from the various lithotypes; e.g. the most mafic components (high Mg#) have been detected almost exclusively in mantles of cpxs belonging to less evolved enclaves. Each compositional population can be attributed to a specific set of magmatic variables, which represent a defined magmatic environment (ME). Cpx-liquid thermometers and barometers have been used in order to investigate the crystallization conditions of the different magmatic environments detected in the Zaro cpx. The investigation of relationships among the magmatic environments enables to: 1) accurately characterize the magmatic component (end-members) involved in the mingling/mixing process and 2) precisely record fluctuations inside the Zaro magmatic system. Lastly, the application of different diffusion modelling approaches allowed estimating the timescales over which the processes that created the zoning occurred.

A petrological and geophysical study of the Mt. Etna summit activity between July 2019 and January 2020

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The activity of Mt. Etna during 2019 and 2020 has been highly variegated, with overall Strombolian explosions of variable intensity from all the summit craters, punctuated by lava flows from the New South East Crater (NSEC) and Voragine (VOR). In this scenario, the most interesting feature was the resumption of activity at VOR after more than three years since the powerful episodes of 2015-2016. We focus on the evolution of volcanic phenomena observed at the NSEC and VOR between July 2019 and January 2020. Over this period, the plumbing system dynamics have been inspected by integrating petrological observations with analyses of the amplitude and source location of volcanic tremor and infrasound data. Textures and zoning of plagioclase and olivine crystals have been used to reconstruct the conditions of magma accumulation and recharge prior to the eruption. Crystals erupted on July 2019 at the NSEC record long-lasting intrusions of magma into the mid-upper section of the plumbing system (between 290-120 MPa), which acted as the main zone of magma accumulation before the beginning of the eruptive activity. Crystals erupted at VOR emphasize intermittent recharge/discharge phases that involved magmas coming from a shallow (<40 MPa), nearly unperturbed magmatic environment, which fed the steady-state Strombolian and effusive activity at the summit for the subsequent months. Petrological evidence exists of a progressive transition from this early phase, in November and December 2019, characterized by substantial equilibrium during magma storage and transport towards a period, in January 2020, dominated by more continuous Strombolian explosions, which resulted from the migration of deeper magmas to the shallow reservoir. Chemical diffusion in olivine has been used as a proxy to estimate the time at which magmatic intrusions have occurred. Our results emphasize a close connection between the recorded seismic signals and magmatic intrusions feeding the eruptive activity.

Violent Strombolian activity vs. caldera forming episodes: the case study of the Spiaggia Lunga welded scoriae at Vulcano (Aeolian Island, Italy)

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During the last 100 kyrs the island of Vulcano has been interested by the progressive formations of two main calderas, called "Il Piano" (48-21 kyrs) and "La Fossa" (27-1 kyrs). During the "Il Piano" caldera forming stage, the re-activation of the semi-circular border faults is associated to the emplacement of small-volume, massive reddish welded shoshonitic scoriae (i.e., Monte Luccia, Spiaggia Lunga, Quadrara eruptions). All these events start with a phreatomagmatic phase producing pomiceous fall deposits and cross-laminated tuff layers due to the generation of PDCs. The aim of the work is to reconstruct the pre- and syn-eruptive dynamics occurring in the magma plumbing systems and their possible connection with the phases of caldera collapse. This has been reached through the integration of geological, petrographic, mineralogical and geochemical investigations on the 50-m-thick welded scoriae of Spiaggia Lunga Ftn. (ca. 24 kyrs), resulting from violent Strombolian activity developed along the SW border of "Il Piano" caldera. By means of textural and compositional (EMPA) investigations on plagioclase crystals, five crystal textures have been recognized: I) oscillatory zoning; II) strongly resorbed cores; III) coarsely-sieved crystals; IV) resorbed rims; V) melt inclusion layers. Their interpretation allowed us to identify the pre-eruptive dynamics leading to the formation of the scoriae blanket, whereas their frequency within each sample led to a petrologic/volcanological reconstruction of the eruptive event. Spiaggia Lunga Strombolian activity has been triggered by a "cryptic" mixing between a shoshonitic magma, residing at Moho depths, and a slightly more basic, hotter, and richer in volatiles magma. During the course of the eruption, a major (plus seven minor) event of decompression on the magma plumbing system have been registered by plagioclase crystals and associated with the collapse of the southwestern border of the "Il Piano" Caldera.

Magmatic processes prior to the 1650 CE explosive eruption at the Kolumbo submarine volcano, Greece

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Kolumbo is the largest of twenty submarine volcanic cones tectonically aligned in the Anydros basin, NE of the island of Santorini, one of the most seismically active zones in the South Aegean Volcanic Arc. It explosively erupted in 1650 CE. Explorative cruises employing ROVs showed the presence of a high temperature (220°C) hydrothermal field with CO_2-rich discharges and accumulation of acidic water at the bottom of the crater (505m b.s.l.). A possible magma chamber was recognized below the crater at depth 9-6 km by seismic data. It is thus fundamental to understand its behavior and how its storage and plumbing systems works, to correctly assess risk for the nearby island of Santorini. We present petrographic, geochemical and isotopic data of samples collected by ROVs and by divers. New Sr isotope ratios on single crystals were recently produced. Most samples represent the juvenile products of the 1650 CE activity, characterizing the different magmas interacting before the eruption. They consist of white rhyolitic pumices with grey and black bands, also including basaltic-andesitic enclaves. Plagioclase, biotite, pyroxenes are the main mineral phases; olivine is found in the mafic enclaves. Minerals show quite complex zoning and a large compositional variability. Fresh lithic lavas were sampled; they have amphibole and can be subdivided in three groups with distinctive petrographic textures that are reflected in their different chemical compositions. They give information on the early history of the volcano and on how the rhyolitic magma could have been generated. Our data suggest the presence of a complex storage system where the most evolved magma differentiated by assimilation and fractional crystallization, undergoing several inputs of mafic magmas. The early batches of new melts initially mixed with the resident ones, whereas the later arrivals only mingled with the rhyolitic magma, thus possibly representing the final trigger of the eruption.

Petrological and geochemical characterization of the Outer Coast Tuff Formation: Unravelling the magmatic processes preceding and triggering Deception Island's caldera - forming eruption (Antarctica)

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Deception Island (South Shetland Islands), discovered in 1820, is one of the most active volcanoes in Antarctica with more than 20 eruptions (including the historic eruptions of 1967, 1969 and 1970) and three documented volcanic unrest events (1992, 1999 and 2014-15) over the past two centuries. Today, Deception Island hosts two scientific bases, which operate every year during the Austral summer and is also one of the most popular tourist destinations in Antarctica. The island consists of a composite volcano with an 8.5 x 10 km centrally located caldera dated as 3,980 ± 125 yr. BP. During the caldera-forming event, between 30 and 60 km3 (Dense Rock Equivalent-DRE) of magma erupted in the form of dense basaltic-andesitic pyroclastic density current deposits, that formed the Outer Coast Tuff Formation, the main syn-depositional unit. Characterizing the magmatic conditions and processes that triggered the huge explosive event is crucial to understand the past (and future) magmatic and volcanic evolution of the island. In consequence, the objective of the present study is to perform an exhaustive petrological and geochemical study (mineral and juvenile glass geochemistry) of the Outer Coast Tuff Formation (OCTF), the main syn-caldera depositional unit. Our primary results confirm the existence of two different magmas coexisting, and interacting, prior to (and during) the caldera-forming event. Mineral analyses also allow shedding further light on the magmatic processes occurring in the magma system before the eruption (e.g. fraction crystallization, magma mixing). This research is part of POLARCSIC and PTIVolcan research initiatives.
This research was partially funded by the MINECO grants POSVOLDEC(CTM2016-79617-P)(AEI/FEDER-UE) and VOLGASDEC (PGC2018-095693-B-I00)(AEI/FEDER, UE). This research is also supported by the PREDOCS-UB grant.

Crystallisation and equilibrium conditions of Mount Amiata volcanic rocks, and their significance in the frame of magma evolution: in-situ chemical, mineral chemistry, major, trace elements and Sr-isotopic data

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The Pleistocene Mount Amiata volcano is part of the Radicofani – Mt. Amiata plumbing system, and it constitutes one of the most important exploited geothermal fields in Tuscany with ca. 88 MW of produced electricity. We carried out a petrological, mineral chemistry and thermobarometric study of the Pleistocene lavas and domes, with the aim of deciphering the crystallisation history of the magmatic system feeding the geothermal field at Mount Amiata. The presence of rounded magmatic enclaves testifies the occurrence of a process in which the fresh mafic hot magma was injected into a cooler and mushy crystallised differentiated one, mixing and mingling with the latter. The first arrival of mafic magma within the differentiated magma reservoir triggered the chemical mixing with the viscous trachydacitic resident magma to form the less differentiated magmas. A reverse differentiation pathway is observed with time of magma emplacement, which is accompanied by decrease of silica contents and increase of MgO and compatible elements passing from early trachydacites to potassic trachybasalt (absarokite). Our results support a two-stage scenario: the first stage was characterised by a magma intrusion, traceable to Radicofani monogenic eruption, forming magmatic sill-shape chamber that differentiated from high-K basaltic-andesite mantle-derived to trachydacite, without chemical assimilation of the wall-rock but with formation of an insulant metamorphic contact aureole cap. The second stage was characterised by the slow and gradual feeding of the magma chamber by a mafic silca- undersaturated mantle-derived magma, which mixed and mingled with the trachydacite. The evolution of melts in the feeding system is mainly controlled firstly by fractional crystallisation processes and, after the arrival of the mafic ultrapotassic magma, by mixing plus fractional crystallisation processes.

An Overview of the Geochemical Characteristics of Oceanic Carbonatites: New Insights from Fuerteventura Carbonatites (Canary Islands)

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The occurrence of carbonatites in oceanic settings is very rare if compared with their continental counterpart, having been reported only in Cape Verde and Canary Islands. This paper provides an overview of the main geochemical characteristics of oceanic carbonatites, around which many debates still exist regarding their petrogenesis. We present new data on trace elements in minerals and whole-rock, together with the first noble gases isotopic study (He, Ne, Ar) in apatite, calcite, and clinopyroxene from Fuerteventura carbonatites (Canary Islands). Trace elements show a similar trend as Cape Verde carbonatites, almost tracing the same patterns on multi-element and REE abundance diagrams. Carbon and oxygen isotope ($\delta^{13}C$ and $\delta^{18}O$) compositions of Fuerteventura and Cape Verde carbonatites share a common isotopic signature, showing typical mantle-derived values and plotting into the so-called "primary igneous carbonatite" box. Although they present slight differences in Sr-Nd-Pb isotopic compositions, Fuerteventura and Cape Verde carbonatites seem to reflect contributions from three mantle components (DMM, EM-I, and HIMU), showing a similar trend in Sr-Pb and Nd-Pb diagrams. $^{3}He/^{4}He$ isotopic ratios of Fuerteventura carbonatites reflect a shallow (sub-continental lithospheric mantle, SCLM) He signature in their petrogenesis, and they clearly differ from Cape Verde carbonatites, i.e., fluids from a deep and low degassed mantle with a primitive plume-derived He signature are involved in their petrogenesis. Future research on the importance of the heterogeneous metasomatism of the oceanic lithosphere (carbonatites occur only on a few islands of the Canary and Cape Verde Archipelagos) and a possible role of the lithosphere thickness could be fundamental to understand why oceanic carbonatites are so rare and are not found in all HIMU-OIB-like archipelagos.

Rapid CO_2-release from magma-carbonate interactions: Why is it important?

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Magma wall-rock interactions are an unavoidable process in Earth's interior. From the generation of magma at depth, during migrations through dykes and sills, storage in a magma chamber until the final ascent to the surface, magma is interacting with the surrounding rocks. The interaction with carbonate-bearing wall-rocks is of special importance due to the thermo-metamorphic release of CO_2. Additional CO_2 exsolution, not only influences magma rheology, degassing behaviour, and magma ascent, but it also might be the reason for the transition from an effusive to an explosive eruption (e.g. Freda et al., 2011). In a recent study, Carr et al. (2018) calculated that as few as 1000 ppm of additional CO_2 might be enough to cause local vapour overpressure and to trigger an eruption. Further studies (of Deegan et al., 2010; Jolis et al., 2013; Blythe et al., 2015) found the timescale of assimilation of limestones and dolostones by magmas to be in the same timescale of eruptive pulses (hours to days). Therefore, the assimilation of carbonate wall-rock might play a crucial role in altering eruptive behaviour, possibly even prolonging eruptions. Despite its importance on eruption dynamics, the influence of key parameters of the carbonate assimilation process (like timescale, pressure, magma and wall-rock composition) are not or only superficially understood. Our new set of experiments, paired with 3D scanning of the experimental samples via Micro CT and chemical analysis via SEM, shed a light on the timescale of the assimilation and on the thermo-metamorphic processes taking place. As an example, we resolved that the CO_2 exsolution from the carbonate clast and the actual dissolving of the clast within the magma are decoupled processes and should therefore be regarded as two independent processes. This indicates that the rapidity of CO_2 release was probably underestimated until now.

Tracking metal evolution in arc magmas: Insights from the active volcano of La Fossa, Italy

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The mineralization potential of arc magmas depends, among other factors, on the timing of sulfide melt saturation relative to magma differentiation and to exsolution of a magmatic fluid phase. In fossil mineralized or barren systems, understanding the evolution of metals along the magma differentiation path is often hindered by late magmatic processes and hydrothermal alteration. To better understand the process of metal evolution "caught in the act" in crustal reservoirs, we analyzed magmatic sulfides and melt inclusions found within eruptive products from the active arc volcano, La Fossa (Vulcano Island, Italy), for the basalt to rhyolite compositional spectrum. We found that, in case of sulfide-undersaturated and volatile-rich arc basalts, metals are scarcely subtracted by degassing during ascent to shallow crustal reservoirs and reach the highest abundances in intermediate magmas (250 ppm Cu). At sulfide saturation the sulfide melt has 34–66 wt% Cu, leading to a dramatic decrease in chalcophile metals dissolved in the silicate melt. After fractionation of only 0.2–0.3 wt% of sulfide in the solid assemblage, the exsolved sulfide is a monosulfide solid solution (pyrrhotite) containing <3 wt% Cu. Metals that do not partition in sulfides (Pb, Zn) increase their concentrations during magmatic evolution until they are sequestered by a Cl-rich aqueous fluid phase exsolved at the rhyolitic stage. The absolute and Cu-normalized concentrations of metals in sulfide inclusions are similar to sulfide accessories in magmatic rocks associated with world-class porphyry Cu systems. Our results demonstrate that the mechanisms governing metal evolution inferred for the magmatic stage in porphyry Cu environments can be also tracked at an active arc volcano, using eruptive products as snapshots of the magmatic evolution. Arc volcanoes can thus be viewed as ideal active analogues when studying crucial processes for the formation of porphyry Cu deposits.

Magma volatile loss drives the energy of eruptions at Mt. Etna volcano

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Olivine-hosted melt inclusions (MIs) from tephra ejected during variably energetic eruptions from the 2013-2018 activity at Mt. Etna were investigated in order to assess the compositional evolution and pre-eruptive volatile budget (H_2O, CO_2, S, Cl and F) of the erupted magmas. Based on major element compositions, we recognize two types of Mis. The type 1 MIs are entrapped in Fo79-85 olivines and have more basic compositions (SiO_2 42.7-45.7 wt.%, CaO 9.9-12.5 wt.%, Na_2O+K_2O 5.1-6.2 wt.%, Mg# 55-60). The type 2 MIs are found in Fo_{69-78} olivines and show more evolved compositions (SiO_2 46.5-51.2 wt.%, CaO 6.1-9.7 wt.%, Na_2O+K_2O 6.2-8.3 wt.%, Mg# 40-54). Dissolved volatile concentrations are rather low (H_2O 0.4-2.4 wt.%, CO_2 46-849 ppm, S 172-3072 ppm, Cl 870-2884 ppm and F 670-1546 ppm) compared to those of magmas erupted in 2001 and 2002-03. Lower H_2O contents are sometimes correlated with depleted SiO_2 contents. This is particularly evident in some type 1 inclusions. Our data point out that inclusions may have experienced diffusive H_2O loss coupled with SiO_2 depletion, while 20-60% of the CO_2 initially dissolved in the melt was lost to the shrinkage bubbles. Restoration of the original SiO_2-H_2O-CO_2 concentrations allowed us to get insights on the magma evolution and degassing. The transition from type 1 to type 2 inclusions occurs between 200 and 100 MPa during crystallization of olivine plus clinopyroxene. At these levels magmas also experienced CO_2 flushing coupled with H_2O degassing, leading to water depletion in the melt and diffusive water loss from the inclusions. Our restored data indicate that initial water concentrations are comparable with those measured for products emitted during the highly explosive 2001 and 2002-03 eruptions. This suggests that the potential in producing highly explosive eruptions primarily depends on degassing dynamics taking place at shallow levels in the volcano plumbing system under open-system degassing conditions.

Experimental insights on Lithium and Boron behaviour during magma degassing

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Volatile species in volcanic systems are known to play a central role in defining both magma properties and eruption dynamics. Lithium and boron are fluid-mobile volatile elements with similar geochemical properties that are strongly affected by the presence of water in silicate melts. The main goals of this study are to establish better Li and B elemental diffusivity and isotopic fractionation in water-bearing, silica-rich melts and to investigate the behaviour of lithium and boron in dependence of magma ascent rates. First, we performed diffusion-couple experiments, at 300 MPa with temperatures ranging from 700 °C to 1250 °C and durations from 0 seconds to 24 hours. Additionally, isothermal decompression experiments were performed from 300 MPa to 75 Mpa (at 1000 °C), with decompression rates between 0.125 and 0.004 MPa/s. All experiments were done in an internally heated pressure vessel. The elemental Li and B concentrations of the end-products were measured by LA-ICP-MS and isotopic ratios were quantified by SIMS. Our data show that lithium and boron have significantly different mobilities, with their diffusion coefficients being respectively ca. 10-10 and 10-14 m2/s. Isotopes data confirm that lithium is subjected to significant isotopic fractionation, due to the fact that 6Li diffuses faster than 7Li (Richter et al. 2003, Holycross et al. 2018). There is no record of boron isotopic fractionation during elemental diffusion in our experiments. Our experimental decompression results confirm that the bubble sizes and distribution (bubble number density) depend directly on the decompression rates. LA-ICP-MS depth profiles, piercing an intact bubble, reveals and enrichment of Li and B in the gas phase during decompression-driven volatile exsolution. Initial SIMS results show that lithium and boron concentrations decrease towards the bubble-melt interface, while no isotopic fractionation was detected.

Phase relationships and water solubility in trachytes and pantellerites from Pantelleria island: an experimental study

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At Pantelleria, pantellerites and trachytes and constitute the vast majority of the outcropping rocks, erupted either as lava flows or explosively. In this study, we present the results of phase equilibria and solubility experiments on trachyte and pantellerite compositions in order to constrain the pre-eruptive conditions of pantescan magmas. Crystallization experiments were performed in the temperature range 680-950°C, pressure 0.5-1.5 kbar, fluid saturation conditions with XH_2O between 0 and 1 and redox conditions around the FMQ buffer. Solubility experiments were performed in a pressure range 0.5- 3.0 kbar, T= 950°C for trachyte and 850°C for pantellerite and water saturation conditions. Results show that at temperature of 900°C pantellerites are well above the liquids regardless the water content while in trachyte, at the same temperature conditions, clinopyroxene is on the liquidus, together to Fe-rich olivine and alkali feldspar. This latter becomes the most abundant mineral phase in both compositions when temperature and melt water content decrease. In pantellerites, Fe-rich olivine is replaced by aenigmatite+quartz, and this reaction appears controlled by melt peralkalinity and redox conditions. Phase equilibria experiments reproduce the mineral assemblage of natural rocks constraining the pre-eruptive conditions for pantellerite magma at ≈ 1 kbar and temperature of 750°C and ≈ 900°C for trachyte magma. Water solubility experiments show similar H_2O dissolved in the melt for both compositions, this implies that the magmatic felsic system of Pantelleria probably evolves close to water saturation conditions.

Cuddia Attalora volcano, Pantelleria island: petrographic and geochemical characterization of a pantellerite explosive/effusive inter-ignimbrite centre

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Pantelleria evolutionary history was characterized by nine ignimbrite forming eruptions, the oldest dated 181 ka, the youngest being the Green Tuff (GT, ~46 ka). During inter-ignimbrite periods, several local centres were active, either effusive or explosive, more rarely both. Cuddia Attalora (CA) centre (~67 ka) is located in the southern section of Pantelleria, on the La Vecchia Caldera annular fault lines. It represents the major eruptive centre (560m a.s.l.) that separated the Mordomo ignimbrite (~85 ka) from the GT. Early erupted pumice fallout deposits were followed by lava flows that built a shield volcano ~3 km in basal diameter. Despite its high potential significance, CA volcano has never been studied in detail; we present the first petrographic and geochemical data, aimed to define the main petrological features of the CA eruptive units and to make some inferences about the pre-eruptive conditions. CA products are mostly buried by GT ignimbrites, with a few small "windows" in the GT coverage allowing to reveal their presence up to 4 km from the source vent, by the occurrence of the distinctive mineral assemblage alkali feldspar + augite + fayalite + ilmenite. All the analysed rocks of this study are pantellerites, with a low peralkalinity index PI (1.1-1.3). The exposed pumice fallout sequence, from bottom to top, shows an increase of the P.I. from 1.1 to 1.3 and a continuous decrease in Zr (from 1636 to 1238 ppm), suggesting that the eruption tapped a not fully homogenized portions of the magma chamber. Geothermometric estimates based on the rare phenocryst assemblage fay + ilm + mt yielded T of 760°C and 800°C for a lava and a pumice sample, respectively. Projection of normative qz-ab-or compositions in the ternary liquidus diagram define temperatures in the range 760-780°C, in accordance with the low PI values, indicating that the CA magma was one of the least evolved that fed local centres, Cuddia Attalora being also one of the most voluminous.

Stratigraphy, textural and compositional features of the Golja Ignimbrite (Main Ethiopian Rift)

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The Plio-Pleistocene volcanism of the Main Ethiopian Rift is mainly characterized by large eruptions of mafic products (transitional basalts) associated with cinder cones and lava flows alternating with greater quantities of felsic products (peralkaline rhyolitic and trachytic pyroclastics), marked by the formation of large calderas in the Rift floor. The distribution of products is generally bimodal, with a limited occurrence of intermediate products. The processes at the base of this bimodality, known as Daly Gap, are still debated. We have characterized the Golja Ignimbrite (~1.2 Ma) in stratigraphic, textural and compositional terms. The main sequence of the ignimbrite, sourced from an uncertain position within the Rift, is characterized by a coarsening upward basal fallout, overlain by an obsidian fiamme-bearing vitrophyre, brecciated at top. This basal portion of the sequence is followed by a weakly to partially welded ash flow, rich in lithics, obsidians, pumice, crystals and glassy fiamme, passing to a thick, unwelded deposit with white pumice and black scorias. Density of the deposit has its maximum value in the basal vitrophyre and progressively decreases, paralleling the variation observed in the aspect ratio of fiamme and black scoria. The microtextural study of the matrix allowed us to describe different eutaxitic structures along the sequence. Preliminary results obtained from microanalysis of glass and minerals suggest the contemporaneous presence of three different types of juvenile glass: black, low-SiO_2 trachyandesite, microcrystalline glass; light-coloured, microlite-free, comenditic to pantelleritic glass; black, locally banded, intermediate high-SiO_2 trachyandesite glass. Basaltic glass is also sometimes found in plagioclase-hosted melt inclusions. The finding of partially evolved melts, together with textural evidences of magma mixing, represent a not common feature for the products of the Main Ethiopian Rift.

Composite magmatic evolution in Eastern Adamello plutons

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The Adamello batholith comprises many different units: among them Corno Alto and Monte Ospedale show a great variety of lithotypes. The Corno Alto is a bowl-shaped magmatic body made up of trondhjemites with minor tonalites and granodiorites. It also includes dioritic enclaves and mafic to felsic dykes. The nearby Monte Ospedale complex exposes diorites, tonalites and granites outcropping over a narrow area. Aplitic to pegmatitic dykes also characterize the area. This geochemical heterogeneity reflects a composite magmatic evolution with multiple components contributing at the differentiation of a mantle-derived picritic melt into a large deep reservoir. During its evolution, this melt is contaminated by either infill of new picritic melt and assimilation of lower crustal rocks producing different co-existing magma batches. Different mixtures of these components generate chemically heterogeneous batches. Each batch is physically isolated from the surrounding ones as it starts to evolve on its own. Injections of picritic melts from the mantle source make these batches progressively lighter; the lightest batches migrate upwards. Differentiation proceeds at shallower depths forming felsic rocks.

Reconstruction of the feeding system of 1991-95 Unzen eruption by amphibole and feldspar-melt thermobarometry

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This work is focused on the characterization of the magmatic feeding system of Unzen volcano (Japan). Amphiboles and melt inclusions in plagioclases phenocrysts are used to gain thermobarometric constraints, by the methods of Ridolfi and Renzulli (2012) and Putirka (2008), respectively. A total of 21 thin sections of the last eruptive period of Unzen (1991-1995) were analysed at the optical microscope, focusing on texture and alteration of amphiboles and plagioclases phenocrysts. 14 thin sections were selected for electron microprobe analysis. A total of 107 amphiboles and 76 melt inclusions/plagioclases pairs were analysed by EMP (Electron MicroProbe) to quantify the major elements and the water content in the glasses. EMP data of the amphiboles were first processed with the "AMFORM.xls" (Ridolfi et al., 2018) to discard any bad analysis and the "Amp-TBX.xls" (Ridolfi unpublished Excel file, update from Ridolfi and Renzulli, 2012) to determine the crystallization conditions. Melt inclusions and related plagioclases were processed with the attached Excel spreadsheet to Putirka et al. (2008) to estimate the crystallization temperature of the melt inclusion and plagioclases. A pressure of 125 MPa was chosen for the melt inclusion-plagioclase pairs, according to the highly differentiated rhyolitic composition of the melt inclusions. Plotting the data into a P-T diagram, most of the amphiboles are in the 790-830°C and 115-160MPa area, conditions of the shallow magma chamber located at 5-8km of depth. These data agree with the P-T data obtained by most of the melt inclusion-plagioclase pairs, also by literature data. However, some amphiboles give values of 870-920°C and 270-300MPa (~9km of depth), while a third population crystallized at 945-960°C and 410-430MPa (~12km of depth). This suggests that the magmatic system feeding the recent activity of Unzen volcano is composed by three different interconnected storage levels.

Recent volcanism in central and southern Afar: a geochemical focus on the Stratoid Formation

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Magmatism along with tectonics plays a key role in breaking up the continental lithosphere, shaping the plate boundary from rifting to the final oceanic spreading. Geochemical, petrological and volcanological studies of the magmatism at rift margins are crucial to unravel the magma genesis and ascent, the mantle source/s conditions and the role of the continental lithosphere during rift evolution.
Situated at the intersection between the Main Ethiopian Rift and the on-land portions of the Red Sea and Gulf of Aden Rifts, the Afar depression is a classic example of a Rift-Rift-Rift triple junction.
Despite several studies having been carried out on the youngest (< 0.6 Ma) rift axial volcanism e.g., Erta ale, Manda-Hararo, Asal, the geochemical characteristics and origin of older Stratoid (~4.5 - 1.1 Ma) and Gulf Basalt (~1.1 - 0.6 Ma) Formations is debated, hence little is known about the evolution of magmatism during rift development. Occupying 2/3 of the depression and reaching at least 1000 m in thickness, the Stratoids are the most voluminous Formation of Afar while the Gulf Basalt are considered to represent a transitional phase between the widespread Stratoid Series and the youngest and localized magmatic activity associated with the graben formation. Previous work proposed that the Stratoids are chemically and volcanologically rather homogeneous while the Gulf Basalt are distinct from the latter based only on volume and morphological observations of the lava units.
In this work we present the first geochemical evidences revealing the internal variability of the Stratoids and their differences with the Gulf Basalts Formations in central and southern Afar. These geochemical constraints are important to understand the variation of the recent (<4.5 Ma) volcanism in the Afar depression. Furthermore, coupled with the know ages, they could also help to unravel the magmatic evolution in time and space of the rift activity.

SESSION 2 - ERUPTIVE DYNAMICS AND EMPLACEMENT MECHANISMS

Conveners:
Laura Spina and Matteo Trolese

From the deposits to the transport and deposition of pyroclastic density currents: the case of the 39.8 ka Campanian Ignimbrite flow, Italy

INVITED KEYNOTE

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One of the main goals of volcanology is to understand physical parameters and dynamics of pyroclastic density currents (PDCs) from their deposits. Here, we present new data about the 39.8 ka Campanian Ignimbrite (CI), Campi Flegrei, Italy. The ignimbrite covers an area of 6000 km2, with a final runout of about 80 km, and the ignimbrite occurs up to ~1000 m above sea level and the current overtopped ridges several hundred meters higher. Despite many studies, the dynamics of this PDC are still debated. In this work, we merge different methods to define the transport and depositional systems of this large pyroclastic flow. Using our recently published isopach map, we developed an isomass map of the CI and we analyzed the mass distribution among the deposits. We used thickness data to study the topological aspect ratio, which is related to the topography, to define the different phases of the PDC. We used clast dimensions to investigate the competence of the current and any blocking due to the Apennine Mountains. Lastly, we analyzed the depositional features of the ignimbrite to better examine the depositional system. From our results, we reproduce the mass partitioning inside the current, which highlights the concentrated lower part, and roughly estimate the mass eruption rate. The transport system consisted of a huge dilute PDC that, thanks to the interaction with the topography, developed a depositional system composed of fluidized dense granular flows. Despite the dilute transport system, the deposits are those typically associated with a concentrated flow due to the uncoupled depositional system. This work helps the interpretations of PDC deposits, which do not necessarily reflect the transport system. Moreover, it can help volcanologists and numerical modelers to link deposit features with models of internal dynamics, giving insights on PDCs.

Formation mechanisms of inflated lava tubes: the case of La Corona (Lanzarote, Canary Islands)

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Lava systems are increasingly leading to interdisciplinary study, especially when these allow to explore these phenomena both on Earth and rocky bodies of the Solar System. Among the many structures that develop in lava fields, some of the most enigmatic are the lava tubes. Those are a peculiar type of lava caves originating from basaltic lava flows. These roofed conducts are very efficient thermal structures channelizing lava transport over long distances. The longest lava tubes are found on volcanic islands (e.g. Hawai'i, Canaries, Iceland, etc.) or on volcanic plateau characterised by a gentle slope (ity over a poorly mobile tectonic plate (less than ~20 mm/yr, during the last 30 Ma). This environment identifies the Canaries as one of the best terrestrial analogues of the Martian one-shell plate volcanism. What makes this inflated lava tube so interesting is a pyroclastic layer, derived by the initial Strombolian activity of La Corona vent and interleaved within the lava flows crossed by the tube. The layer follows the tube for at least one third of its extent and we speculate that it could have been pivotal for the inception of the inflation process. By analogy, similar geological settings could be favourable for the formation of lava tubes on rocky bodies like Mars and the Moon, where weak layers of pyroclastic deposits or fine regolith are thought to be common.

Paleomagnetic dating of pre-historic lava flows from the urban district of Catania (Etna volcano, Italy)

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In active volcanoes whose slopes were historically inhabited, determining the ages of past eruptions is of pivotal importance for investigating the relationships between eruptive phenomena and human settlements. During its almost three millennia-long history Catania, the biggest city lying at the toe of Etna volcano, was impacted and partly buried only once by the huge lava flow emplaced during the 1669 AD Etna flank eruption. However, other lava flows reached the present-day Catania urban district in pre-historic ages, before city foundation in Greek times (2,679/2,678 yr BP). In this work, the Holocene lava flows of Barriera del Bosco, Larmisi and San Giovanni Galermo, exposed in the Catania urban district, were paleomagnetically investigated at 12 sites (120 oriented cores). Paleomagnetic dating is obtained by comparing flow-mean paleomagnetic directions to updated geomagnetic reference models for the Holocene. The Barriera del Bosco flow turns out to represent the oldest eruptive event, and is paleomagnetically dated to the 11,234 - 10,941 BP and 8,395 - 8,236 BP age intervals. The mean paleomagnetic directions from San Giovanni Galermo and Larmisi flows overlap considering statistical uncertainties. This datum, along with geologic, geochemical and petrologic evidence, implies that the two lava flows can be considered as parts of a single lava field erupted in a narrow time window between 5,494 and 5,387 BP. The emplacement of such a huge lava flow field may have buried several Neolithic settlements, thus explaining the scarce occurrence of archaeological sites of that age found below the Catania town.

Physical and compositional magma gradients into the conduit during the 1st February 2014 eruption at Tungurahua volcano (Ecuador): insights from volcanic bombs

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Vulcanian events are very common at many volcanoes around the world. This type of eruption generates a wide variability of bombs and blocks, preserving information that can be very useful to get insights into the conduit processes that strongly control the dynamics of this activity. Here we present data of one of the most important vulcanian event of the last eruptive interval of Tungurahua volcano (Ecuador), occurred on 1st February 2014. The failure of a conduit plug marks the abrupt onset of the eruption, resulting in a highly energetic explosion and fountain collapses that generated block-and-ash flows. Four different types of block and bombs were found in PDCs deposits: dense blocks (DB), breadcrust bombs (BCB), cauliflower bombs (CFB) and foliated, banded bombs (FB). All the different types of bombs have homogenous andesitic bulk-rock compositions but different, highly evolved matrix glass compositions ranging from rhyolitic for BCB to dacitic for CFB and DB, suggesting the occurrence of different extent of crystallization within the conduit. The differences in groundmass glass composition are also accompanied by important variations in the textural and morphological characteristics of each type of bomb, thus suggesting the importance of pre- and syn-eruptive degassing-induced crystallization. The wide variability of pattern surface cracks and external morphologies between volcanic bombs also reflects different conditions of formation from a same magma composition, allowing to make inferences on the different mechanism of formation of BCB respect to CFB. All these observations are relevant to derive a possible model for 1st February 2014 event for which a cyclical densification of the uppermost portion of the conduit allowed localised pressurization. The simultaneous ejection of different types of bombs reflects the existence of crystallinity and volatile gradients into the conduit during magma ascent, which strongly controlled eruption dynamics.

Central Mediterranean volcanism during marine isotope stages 7 and 6 (250-170 ka): a new tephra record from Fucino Basin, central Italy

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Tephra layers preserved in lacustrine and marine sedimentary successions provide fundamental integrative information for the reconstruction of volcanic explosive history and dynamics. Central-southern Italy represents an optimal setting for the employment of the tephrostratigraphic method thanks to the combined presence of several Apennine intermountain basins and peri-Tyrrhenian volcanic systems. Among these basins, the Fucino paleolake, with its long and continuous Quaternary sedimentary succession, was found to host rich tephra sequences that span at least the last 430 kyrs. Here we present a new tephra succession from Fucino basin spanning the 250-170 ka time interval, corresponding to the marine isotope stages (MIS) 7 and 6. The investigated tephra layers has been characterized by means of several analytical techniques, such as EPMA, LA-ICP-MS, TIMS and 40At/39Ar dating, which provided a full geochemical fingerprint. The MIS 7-6 Fucino tephra were backtracked to their corresponding volcanic sources, which include Vulsini, Vico, Sabatini, Ischia and Campi Flegrei volcanic systems. While some of these tephra have been correlated to their specific proximal units, other layers are currently not documented or described in near vent sections, thus highlighting previously unrecognised paroxysmic events at these volcanic systems. The tephra sequence here described thus provides new integrative information for the reconstruction of the explosive history of Italian volcanoes during the investigated interval. Finally, our record is compared with other terrestrial, lacustrine and marine tephra archives, in order to consolidate and update the central Mediterranean tephra network.

Syn-depositional erosion and clast incorporation from ash-rich PDCs: an integrated sedimentological and geochemical analysis with laboratory experiments on the Brown Tuffs eruptions (Vulcano, Italy)

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The Brown Tuffs (BT) are ash-rich pyroclastic deposits produced in the last 80 ky time span by pulsating hydromagmatic eruptions from the La Fossa Caldera on Vulcano and widespread with variable volumes over the Aeolian Archipelago and Capo Milazzo peninsula (Sicily). They represent an exceptional case-study to investigate the processes that drive erosion and deposition in ash-rich PDCs and their interactions with the substratum. The BT field investigation, along with sedimentological analysis, grain-size and componentry study and grain-specific volcanic glass compositional data, has been carried out on BT units from Lipari and Vulcano and point out to processes of erosion and clast incorporation in the basal portions. This erosional behaviour was also confirmed by small-medium scale laboratory experiments performed with the GRANFLOW Simulator (LAIMA-UASLP, Mexico). On the field, most of the BT depositional units are characterized at the base by mixing bands with pumice, scoria and lithic clasts ripped-up from the underlying pyroclastic units that indicate erosion and incorporation of loose material from the beds and also highlighted by minor populations of glass of compositions similar to the corresponding underlying deposits, also reported in depositional units where mixing bands are not visible at a macroscopic scale. Syn-depositional shear structures, like undulated, recumbent flame and rip-up structures, are visible at the base of most BT depositional units and provide indications on the approximate local south-to-north direction of the currents and the conditions of high concentration of these PDCs. The same structures are observed in the experimental deposits performed and their elongation direction can be used as an indicator of the flow directions, thus the recognition of these structures up to the northern sector of Lipari indicates that the BT PDCs, travelled up to distances of tens km from the source area with high capacity of impact over the territory.

Mechanisms of ash production and recycling during low-energy, mid-intensity eruptions at Copahue volcano (Argentina)

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Volcanic ash is the result of extensive magma fragmentation during eruptions. It depends upon a combination of magma properties (rheology, vesicularity, permeability, gas overpressure) and the possible involvement of external fluids during magma ascent. However, fragmentation processes during the ash-dominated, low-to-mid intensity eruptions are still a matter of debate. Combination of morpho-textural data of the erupted ash with geophysical data on the activity can inform about the energy of the activity as well as on the mechanisms of ash production and dispersal. The phase of heavy ash emission occurred during March 2016 at Copahue volcano (Argentina) generated a very low infrasonic amplitude, corresponding to low exit velocity and low magma overpressure. The apparent unbalance between measured geophysical parameters and the intensity of the activity raises a number of questions concerning the links among acoustic pressure, gas overpressure and efficiency of magma fragmentation. Generally, magma-water interaction is supposed to be the main process of magma fragmentation at Copahue. Conversely, our data on ash texture indicate that a process of magma volatile exsolution under low overpressures actively controlled the fragmentation during the investigated eruptive stage. Ash componentry also revealed that a large fraction of deposit consisted of recycled material. Therefore, comparing these results with geophysical information, we interpreted the activity as influenced by a process of energy buffering, operated by the passage of the erupting mixture through a thick layer of granular, ash-bearing crater infilling produced by the ash recycling processes. The importance of this abundant hot, vent-hosted material for the convective stability of the eruptive plume and for the ash dispersal was highlighted, with direct consequences for the assessment of the related hazard and management of eruptive crises.

Volcanic supersonic jets: an experimental study of the effect of particles on the shock cell structure and acoustic emissions

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Explosive volcanic eruptions eject a mixture of gas and pyroclasts into the atmosphere at a range of velocities. Directly above the vent, in the gas-thrust region, a supersonic jet may be generated. To improve our understanding of these volcanic supersonic jets and, consequently, to get a better estimate of volcanic hazard, we simulated small-scale explosive eruptions in the laboratory using a shock-tube. Other similar experiments were run in the past i) to find correlations between the key parameters and the physical boundary conditions usually met during these eruptive events, ii) to compare the results obtained with field observations. Here we focused on the interaction between a supersonic jet and the particle load within it. The jet was recorded by a high-speed camera and its acoustic emission (jet noise), produced by the flowing gas, by microphones. Video recording enabled us to find the particle velocity and to quantify the particle load over time. As to the audio recording, by applying fluid mechanics models, we were able to associate specific frequencies (Broad Band Shock Noise, BBSN) emitted by the interaction between shock cells and the turbulence in the supersonic jet with the velocity and its oscillation to varying particle concentration over time. The results replicate what seen in previous experiments (i.e., temporal evolution of particle exit velocity fitting well with models; occurrence and shifting of shock cells observed during the supersonic phase of the jet; shock cells shifting upstream in presence of particles), adding new information (i.e., apparent non-interdependence between particle exit velocity and particle concentration in the jet; shock cells shifting specularly resembling the BBSN peak frequency trend over time). We showed that scaled laboratory experiments are a viable tool to determine crucial parameters as the amount of pyroclasts in a volcanic jet and their exit velocity, based solely on the recorded acoustic signal.

Crystallization of peralkaline rhyolitic magmas: rheological implications for the Pantelleria system

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Pantelleritic magmas are strongly peralkaline rhyolites with a lower viscosity than calc-alkaline rhyolitic magmas, but they often show wide variations in eruptive style from effusive to highly explosive eruptions. Particularly, the recent volcanic history of the Pantelleria volcanic system shows eruptions with different eruptive style: from Strombolian eruptions of Cuddia del Gallo/ Randazzo and Fastuca Pantellerite up to the Green Tuff Plinian eruption. The processes that promote fragmentation and explosive eruptions of pantelleritic magma remain unclear and are subject to debate. Crystallization has a key control on the magma rheology at pre- and syn-eruptive conditions and on the volcanic eruptive styles of alkaline magmas. Therefore, here we present a review of equilibrium and disequilibrium crystallization experiments of peralkaline rhyolites, focussing our attention on crystallization of alkali feldspar (Afs) and clinopyroxene (Cpx), which are the main crystal phases in Pantelleria products. In our study we compare the experimental data with data obtained from natural products of the Strombolian eruptions of Cuddia del Gallo/ Randazzo and Fastuca Pantellerite, and of the Green Tuff Plinian eruption in order to constrain their pre-eruptive conditions. Based on the pre-eruptive conditions (50-120 MPa, 700-800 °C, 2-6 wt% H_2O), we investigate how pre-eruptive temperature, H_2O_{melt}, crystal fractions (Φ) and crystal aspect ratio can influence the rheological behavior of pantelleritic magmas. Φ of the natural products ranges between 0.08 and 0.15 (Afs and Cpx phenocrysts). Our results indicate that the low pre-eruptive crystal fractions (0.08 and 0.15), temperatures between 700 and 800 °C and the decrease of H_2O_{melt} during magma ascent can promote a significant change in magma viscosity (up to 106-107 Pa s). This may lead to brittle fragmentation promoting explosive eruptions.

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

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Since the heat amount available in a volcanic system strongly impacts eruption dynamics and deposit characteristics, the study of pyroclastic material is fundamental to get information on their thermal history and ultimately address the hazard potential of both effusive and explosive events. Relaxation geospeedometry techniques using a Differential Scanning Calorimeter (DSC) on glasses are the prevailing techniques for retrieving cooling rates (q). This methodology allows accessing the thermal history of glassy phases by revealing the cooling kinetics across the glass transition recorded by the glass fictive temperature (Tf; i.e., the temperature at which the liquid structure appears frozen on the timescale of observation). Conventional DSC (C-DSC) devices explore limited cooling rates (below 0.5 K/s) and often need extensive extrapolations to be applied to those affecting natural volcanic materials. This study introduces a universal technique for retrieving cooling rates by combining Conventional and Flash DSC (F-DSC). The latter is a novel apparatus that allows gaining information on the glass transition kinetics under ultra-fast cooling rates (from 3 to 30000 K/s). We tested on silicate and fluorophosphate glasses and expanded over six orders of magnitude of cooling rates the "unified area-matching" technique for Tf evaluation. This methodology has been then used to parameterize the Tf dependence on the applied cooling rate. Analysis on standard and synthetic glasses allowed us to successfully model q up to 1000 K/s and provide a composition- and cooling rate-independent shift factor relating cooling rates to melt viscosity. Therefore, the proposed strategy represents a significant improvement for the study of fast- and hyper-quenched samples, better capturing and constraining the cooling rates experienced by volcanic materials following both sub-aerial and submarine eruptions.

The Volcanological In-Situ Deformational Instrument (VIDI)

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A unique low load, high temperature apparatus is designed to investigate magma rheology and directly observe deformation of the sample at temperatures of volcanological interest. The new apparatus, that we call Volcanological In-situ Deformation Instrument (VIDI) is developed to perform vertical uniaxial deformation at high temperature (up to 1100 °C) on natural silicate melts. The base unit is a uniaxial press equipped with a furnace in which a sapphire window allows the visual inspection and camera recording of the sample subjected to deformation. This unique characteristic allows to characterize the rheology of the sample in a range of viscosity from 10^8.5 to 10^11.5 Pa s and relate rheological data to deformation mechanisms. Viscosity is calibrated by measuring cylindrical samples of 20-40 cm in height and 10-20 cm in diameter of NIST Standard Reference Material® 717a Borosilicate Glass at temperature between 540 and 625 °C and strain rates between 5 x 10^-5 and 1 x 10^-3 s^-1. Viscosity standard values are reproduced with an error of ±0.21 log Pa s. VIDI apparatus can be also employed to perform accurate studies on bubble-bearing melt samples, by allowing an observation of the processes occurring above the glass transition temperature (i.e., viscous softening, degassing and outgassing) prior or during deformation. A first test of a foaming natural obsidian is performed on a cylindrical sample from the Rocche Rosse lava flow (Aeolian Arc, Italy). Experiment involves in-situ degassing at T =850 °C and subsequent deformation at T =800 °C at a constant strain rates of 10^-4 s^-1. The analysis of the strain partitioning on the sample during the deformation indicates a progressive increase of piston-sample contact area, while the sample maintains a cylindrical shape. This new instrument can lead to a complete set of experimental results that can be directly applied to natural processes.

An extended rheological map of pāhoehoe - ʻaʻā transition

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The pāhoehoe–ʻaʻā morphological transition involves a change in the rheological response of the magmatic suspension from pure viscous to complex rheological behavior, resulting in the development of tear-apart features. Here, we present a suite of concentric cylinder experiments aimed at studying the effects of cooling and shear rates on the rheology of a phonotephrite melt in response to crystallization. Experiments were conducted at: i) isothermal subliquidus temperatures of 1,167 – 1,189 °C and shear rates of 1 – 3 s-1; ii) constant cooling rates of 1 – 10 °C/min and shear rates of 1 – 20 s-1. We defined the viscosity-temperature-time window of lava solidification, as well as the transition from coherent flow to shear localization and physical separation (i.e., viscous rupture). Through this approach, we mapped the processes and timescales affecting pāhoehoe–ʻaʻā transition in natural lavas at variable cooling and shear rates. Under disequilibrium conditions, as the cooling rate increases, both crystallization onset and viscous rupture occur at lower temperature and earlier in time. Moreover, the time to reach the crystallization onset and viscous rupture also decreases with increasing shear rate. Both increasing cooling and shear rate reduces the critical crystallinity required for viscous rupture, a consequence of the non-linear interplay between temperature, crystallization kinetics, and melt viscosity. This outcome expands our knowledge on compositional, thermal, and rheological changes in phonotephritic systems. In addition to shear rate and apparent viscosity, comparison with previous basaltic measurements indicates that the pāhoehoe–ʻaʻā transition is sensitive to the composition and cooling path of lavas.

3D sample modeling from difficult access samples applying Agisoft Metashape Standard

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Some geological samples, for example from active volcanos, are difficult to be compiled. Its conservation so far has been solved by different supports, among others 2D images and description files. In this project, we are currently working on the conservation of rock samples applying complex digital method, such as 3D sample models. These models also offer a solution for the incising demand of teleworking associated to the current socio-sanitary situation related to the COVID-19. With the aim of complement the GEO3BCN-CSIC Antarctic digital files and to create a digital repository, it has been generated various 3D digital models of different samples from the Deception Island (Antarctica). Our final objective is offering a solution to conserve the original appearance of these samples and to allow free access to them. The digitization of the samples has been carried out using a NIKON D5600 camera with a resolution of 6000 x 4000 and the Agisoft Metashape Standard program. Depending on the sample size, between 30 and 60 images have been processed, with the use of photo alignment, dense cloud, mesh and texture. This research is part of POLARCSIC and PTIVolcan research initiatives. It was partially funded by the MINECO grants POSVOLDEC (CTM2016-79617-P) (AEI/FEDER-UE) and VOLGASDEC (PGC2018- 095693-B-I00) (AEI/FEDER, UE) and it is also supported by the PREDOCS-UB grant.

Construction of a chronostratigraphic database for the study of the eruptive periodicities of the volcanic districts of the Mediterranean area from the Pleistocene to the present

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Tephrostratigraphy and chronostratigraphy allow to correlate the proximal and distal deposits with each other and with the related eruptions and allow to date in an absolute and relative way paleoclimatic and sedimentary events. This project has as its initial goal the creation of database of individual volcanic districts and a general database that, allowing a realistic reconstruction of the eruptive history of the volcanic districts in the Central Mediterranean area from the Pleistocene to the present, and an evaluation the impact on the consequent volcanic hazard. Through the study of the available records, it will be possible to study cyclical behaviors and non-stationarities of the various volcanic districts, correlating these behaviors with possible external factors and to identify the areas exposed to the highest hazards in a civil protection optic. In these first months of research, were created database of the most complete stratigraphic records present in the Mediterranean area, such as Lake Ohrid, Lake Monticchio and the Fucino basin (Lezine et al., 2010; Wulf et al., 2008; Giaccio et al., 2017). These database are the grouping of the layers found during the coring in these points of interest and have been divided and sorted according to their age, dating method, their thickness and their origin. One of the critical points work is the analysis of space-time completeness, due to the large amount of data present on a regional scale and the potential impact of high-altitude winds and the eruptive magnitude variability. To solve these problems, statistical analyzes are performed on high-altitude winds, useful for defining the statistics of the different directions and different wind intensities during the year through the Matlab programming language. These analyzes allow us to quantify, for each volcanic district, the probability that eruptions of different magnitudes can be recorded in the stratigraphic sequence in the areas of interest in the Mediterranean.

Tephrochronology and provenance of an early Pleistocene (Calabrian) tephra from IODP Expedition 374 site U1524, Ross Sea

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Pyroclastic deposits from explosive eruptions are preserved in the offshore sedimentary record of the Southern Ocean surrounding Antarctica. Consequently, marine tephrostratigraphy offers a critical resource of data for volcanological reconstructions including age and recurrence of eruptions, intensity/magnitude, and eruptive dynamics, and for the assessment of the potential volcanic hazards posed by the ash-forming eruption at high southern latitudes volcanoes. During the International Ocean Discovery Program Expedition 374 in the Ross Sea, Antarctica, was found a 20 cm-thick tephra layer intercalated in the marine sediments recovered at Site U1524. We present here a full characterization of this tephra including tephra texture, mineral paragenesis and major- and trace-element composition on individual glass shards. The tephra age was also constrained by the ^{40}Ar-^{39}Ar method on sanidine crystals. ^{40}Ar-^{39}Ar data indicate that a best age estimate of 1.282±0.012 Ma, based on both single-grain total fusion analyses and step-heating experiments on multi-grain aliquots. The tephra is characterized by a very homogeneous rhyolitic composition and a peculiar mineral assemblage, dominated by sanidine, quartz, and minor aenigmatite and arfvedsonite-riebeckite amphiboles. The tephra from Site U1524 compositionally matches with a c. 1.3 Ma, rhyolitic pumice fallout deposit cropping out on the rim of the Chang Peak volcano summit caldera, in the Marie Byrd Land, located c. 1300 km from Site U1524. This contribution offers important volcanological data on the eruptive history of Chang Peak volcano and adds a new tephrochronologic marker for the dating, correlation, and synchronization of marine and continental early Pleistocene records of West Antarctica.

Completing the eruptive record of Deception Island (South Shetland Islands, Antarctica) by describing the ash layers located in proximal marine sediment cores

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Deception Island (South Shetland Islands) is one of the most active volcanoes in Antarctica where a future eruption is very likely to happen. The characterisation of volcanic ash layers may provide valuable information to: (i) determine the size and explosiveness of past eruptive events, (ii) assess the extent of their related hazards; and (iii) complete the eruption record of the island. Here, we present results of the characterization of the ash layers found on five marine sediment cores drilled proximal to Deception Island (less than 40 km). The final aim is to trace isochronous tephra horizons between the studied cores and try associating them to their respective eruptive events. First, we carried out a granulometry analysis of each sampled layer and characterized the morphology of the fragments. The results indicate that the reworking effect by turbiditic currents has not affected the information necessary for correlation. The petrography has highlighted three main different types of volcanic glasses. Type 1 glasses, dark coloured, have low contents in microcrystals and vesicles. Type 2, brown coloured, have a higher content in microcrystals and the fragments usually have a fluidal texture; the vesicle abundance is variable. Type 3, yellow coloured, are usually rich in microcrystals and vesicles, and have fluidal texture. In all families, the mineralogy of the microcrystals is mainly plagioclase (90%), pyroxene and olivine. The longest core (120 cm long) contains 15 layers, the deepest ones (113, 115 and 120 cm depth) may be associated with a period of abundant volcanic activity around 2000 years BP.
This research is part of POLARCSIC and PTIVolcan research initiatives; and was partially funded by the MINECO grants VOLCLIMA (CGL2015-72629-EXP) and POSVOLDEC(CTM2016-79617-P)(AEI/FEDER-UE). Analyzed tephra samples and sediment cores were provided by the rock repository of the Instituto de Ciencias del Mar del CSIC (ICM-CSIC) (http://gma.icm.csic.es/ca/dades).

Stratigraphy of the volcanoclastic succession of the "Spiaggia di Pollara Formation" at Salina (Aeolian Islands, Italy)

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The "Spiaggia di Pollara Formation" is a volcanoclastic sequence mantling the products of the last activity at Salina island (ca. 15 ka), now forming a spectacular 80-m-high cliff on the western part of the island. It is mainly constituted by products coming from the erosion of the previously emitted products and related in literature to deposition within a lacustrine environment. The aim of the work is the reconstruction of the main transport and depositional mechanisms forming this succession, by means of an integrated methodological approach including stratigraphical observations, petrography and sedimentological features. The geological study carried out on the field has allowed the reconstruction of the stratigraphic sequence and to identify the main structures. The succession resulted as a complex alternation of up-to-1-m-thick layers with prevalent coarse pumices and lithics, characterized by a low lateral continuity and erosional surfaces. Laboratorial work consisted of: a) study of particle size distributions; b) components analysis of the coarse fraction (>4mm ø); c) petrographic study of thin sections; d) morphoscopic analysis at SEM. The study of particle size distributions revealed that most samples are poorly/very poorly classed, polymodal and mainly made up of fine/medium gravel. Components analysis and the observation of the thin sections evidenced the prevalent presence of juvenile material from Upper Pollara throughout the sequence (banded and biotite-bearing pumices) and ash accretions on the juvenile and lithic surfaces. SEM analyses also allowed to identify weathering features (pitting) and coating patinas. All integrated data suggest that the epiclastic deposits are not attributable to a lacustrine environment but to a system with a high-energy transport, such as a complex small-order system of torrents. Further studies are required to confirm this hypothesis.

High-resolution video characterisation of Vulcanian eruption plumes at Sabancaya volcano, Peru

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Sabancaya volcano (Peru) is an intermediate-composition stratovolcano in the Central Volcanic Zone of the Andes. Since November 2016, Sabancaya has been producing multiple Vulcanian explosions per day, whilst a lava dome had been concurrently growing within the crater. Vulcanian eruptions are short-lived volcanic explosions thought to result from rapid decompression of a conduit containing pressurized magma. Eruptions at Sabancaya typically have a duration from tens of seconds up to a minute and consist of a release of ash and gas, which rises as a plume to heights of 2-3 km above the vent. Our project represents a multidisciplinary approach to determine eruption dynamics and physical parameters, combining high resolution video analysis, quantitative measurements and numerical modelling. We investigate high resolution videos of selected eruptions from Sabancaya during July and August 2018, with the aim of extracting quantitative information on the eruption source parameters and entrainment of atmospheric air into the plumes, thus improving our understanding of the eruption dynamics. Image processing methods are used to extract geometric parameters, such as the plume height and radius as a function of time, and to provide information on turbulent structures within the plume. Various image analysis methods have been explored using ImageJ and Matlab in variable weather conditions. A geometric calibration has also been applied to convert pixel locations into physical coordinates, considering camera orientation and inclination, as well as the local wind field. Such a calibration allows for measurements of plume height, shape and rise velocity that are ultimately used to determine the erupted mass for each explosion. Finally, descriptions of air entrainment are made by comparing these results with experimental observations and simple theoretical descriptions with existing models from the literature.

Multi-parametric characterization of intermediate-size ash/gas-rich explosive activity at Batu Tara Volcano (Flores Sea, Indonesia)

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Batu Tara is an active but poorly studied volcano located in the Lesser Sunda Archipelago (Indonesia). During its most recent, long-lasting eruptive phase (2006-2015), Batu Tara exhibited frequent short-lived intermediate size ash/gas rich explosions similar to those of Stromboli Volcano (Italy). On September 2014, we performed a multi-parametric campaign with the twofold aim of 1) expanding the baseline knowledge of a scarcely monitored volcano and 2) shedding light into the characteristics of intermediate size ash/gas rich volcanic eruptions. Synchronized acoustic, thermal and visible high-speed imaging data were acquired in order to parameterize spatial and temporal properties of each explosive event with respect of: i) maximum height and ejection velocity of bombs and plumes, ii) duration, iii) amplitude of acoustic and thermal transients, iv) acoustic and thermal energy, and v) spectral features of the acoustic signals. The spectral properties of the acoustic events, clustered in different families, suggest a closed-open resonance of the uppermost conduit section, likely in response to the arrival of over-pressurized gas at the free magma surface with various degrees of overpressure or conduit flaring. Comparative analyses of acoustic and thermal energies with previous observations of intermediate-size explosions at other volcanoes reflect the source complexity of this eruptive style transitional in between the Strombolian and Vulcanian end-members.

SESSION 3 - GEOLOGY AND STRUCTURE OF VOLCANOES

Conveners:
Federico Galetto and Mariangela Sciotto

Multi-disciplinary analysis of ground deformation on the eastern flank of Mount Etna

INVITED KEYNOTE

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Mount Etna is located on eastern Sicily on the border of the collision zone between the Eurasia and Nubia plate. The regional geodynamic framework is characterized by two active tectonic domains: a compressional one oriented N-S and an extensional one oriented approximately WNW-ESE. These two domains, together with the volcano-tectonic one, generated a tectonic system which is unique in the world. It exhibits a complex system of faults prevalently on the eastern flank of the volcano. Th eastern flank of Mount Etna is the most active area of the volcano in terms of deformation and seismicity, because the velocities are at least one order of magnitude greater than the area surrounding the volcano due to the eastward sliding of this flank.
The monitoring and analysis of the acceleration which occur on the eastern flank of Mount Etna is the keystone to understand the volcano tectonic dynamics that involves the instability of this flank in a densely inhabited area. In this context the Istituto Nazionale di Geofisica e Vulcanologia – Osservatorio Etneo (INGV-OE) created one of the most sophisticated and complete monitoring networks in the world in terms of number of multi-disciplinary station. Since 2014, the GeoDynamic & GeoMatic Laboratory (GD&GM-LAB) of the University of Catania started to create many GNSS little networks, belonging to the UNICT-NET, in order to determine the offsets occurring on the blocks of each fault of the eastern flank. In 2020, in order to have a complete analysis of deformation, INGV-OE and the GD&GM-LAB started a strictly collaboration to share data and ideas to improve the understanding of the volcano-tectonic dynamics of the eastern flank.
Currenctly, the UNICT-INGV research team is focused on the analysis of the velocity fields from GNSS time series, InSAR data and photogrammetric surveys through Unmanned Aerial Vehicle (UAV).

Vertical ground deformation of the Campi Flegrei offshore caldera based on paleo-sea level markers

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Appraisal of morphodepositional markers tied to ancient sea-levels in high-resolution seismic profiles together with geo-archaeological markers along the coast of the Pozzuoli Bay provided insights into the vertical deformation of the submerged part of the Campi Flegrei caldera (Southern Italy). The collapse of the central part of the Campi Flegrei caldera is associated with the eruption of the Neapolitan Yellow Tuff (NYT) at ~15 ka. The NYT caldera collapse was followed by central dome resurgence associated with alternations of fast uplift and subsidence displacements that accompanied with discrete phases of intra-caldera volcanic activity. Previously, the evolution of ground movement in the Campi Flegrei caldera has been reconstructed using marine deposits uplifted onland or archaeological evidence and historical accounts and thus offers a mainly 2D appraisal of the deformation pattern. However, a complete reconstruction of post-collapse deformation suffers of the limitation that nearly two-thirds of the caldera are submerged beneath the Pozzuoli Bay. We contribute to fill this gap by providing a reconstruction of offshore and coastal deformation through estimation of the vertical displacement of morphodepositional markers in high-resolution seismic reflection profiles and geoarchaeological markers directly surveyed at shallow depths. Our interpretation reveals the occurrence of different sediment stacking pattern whose provides evidence of rapid and oscillating ground movements. Whereas the offshore morphodepositional markers provide displacement information for the last ~12 ka, for the last ~2 ka our interpretation is supported by ancient Roman sea-level indicators. The multi-dataset analysis has allowed disentangling the signal related to the post-caldera dynamics from a broader deformation signal that affects this part of the extensional margin of the Apennines.

Interaction between structures and hydrothermal fluids in the Solfatara area: new insight from integrated geological, geophysical and volcanological study

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The Agnano Plain hosts the Pisciarelli Fumarole Field and Solfatara volcano and represents, to date, the most active sector of the Campi Flegrei caldera. During the last epoch of activity, this area was site of volcanism consisting of effusive events, as Mt. Olibano and Accademia lava domes; phreatic, phreatomagmatic and strombolian eruption as S. Maria delle Grazie and Solfatara. At the present, this area is affected by a widespread fumarolic hydrothermal activity and by a great number of earthquakes. Geo-volcanological and structural studies, of this sector of Campi Flegrei caldera, reveal the occurrence of a great number of faults, which localize the main fumaroles and mud pools. In order to better define the structural pattern of this sector of Agnano caldera, also in the subsurface, electrical resistivity tomographies (ERT) were performed in Solfatara crater, Pisciarelli Fumarole Field and Via Antiniana. The results of the electrical investigations allowed to highlight the complex structural array consisting of normal faults with surficial expression, blind normal faults, and related damage zones, as well as to disclose the relationships among rising hydrothermal fluids and the mapped structures. ERT results have been used also to distinguish between fluids storage zones and upstream-flowing areas. The reconstructed structural images show a complex hydrothermal system formed by a mix of upwelling gas, condensed, and meteoric water. The detected faults and at their crossing, where highly fractured rocks occur, act as the preferred pathway for hydrothermal fluid circulation, whose surface expression is testified by the occurrence of aligned fumaroles and by the strong hydrothermal alteration affecting the rocks of the whole area. The results of this multidisciplinary investigation provide new elements of knowledge on the active structures in this sector of Campi Flegrei caldera, which are of fundamental importance for the forecast of future eruptive scenarios.

Insights on the cyclic eruptive behavior and stress field conditions at dome volcanoes by coupling observational data with numerical modelling: the example of Fuego de Colima volcano (Mexico)

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In the last decades the investigation on the cyclic activity at dome volcanoes has improved with the availability of the satellite thermal data for observing volcanic activity, combined with numerical modeling and geophysical studies. We studied the fluctuations in discharge rate at Fuego de Colima (FdC, Mexico) during the last 20 years, combining the MODIS data and published observational ones. By using spectral and wavelet analyses, we detected a multi-term periodicity. To investigate the non-linear cyclic eruptive behavior, we provided numerical simulations considering a magma feeding system composed of a dual or a single magma chamber(s) connected to the surface. By exploring cases in which the periodicity is controlled by (i) the coupled deep–shallow reservoirs, (ii) the single chamber, and (iii) the elastic shallow dyke when it is fed by a fixed influx rate or constant pressure, we reproduced the periodicities in discharge rates, inferring a first-order picture of the FdC feeding system. A 2D finite-element modelling was applied to investigate the stress field conditions, considering either one or two magma chambers connected to the surface via dykes or isolated in the elastic host rocks. Beside and beyond the importance of geological data in FEM simulations, the model runs using the complex feeding system geometry and tectonics showed how the present-day volcanic system can be considered in equilibrium from a stress state point of view, in agreement with the long-lasting open conduit dynamics that have lasted since 1913.

Repeating earthquakes and GPS data as tools to investigate the fault dynamics: a case of study from Pernicana fault system (Mt. Etna, Italy)

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Active faults give rise to seismicity and ground deformation, whose study helps shed light on the fault dynamics. As for seismicity, repeating earthquakes, sharing the same source location and mechanism, act as repeatable sources that occur at the same spot but at different times. Hence, they are useful to reconstruct the fault dynamics. In this work, we analysed the repeating earthquakes that occurred at Mt. Etna during 2000-2019, along the Pernicana Fault. Mt. Etna is characterized by several seismogenetic volumes showing different rates of occurrence and focal depths. Its eastern flank is crossed by several fault systems, among these, the Pernicana Fault, a transtensive structure, represents the northern boundary. The dataset analysed in this work is composed by 1863 VT earthquakes with magnitude from 0.5 to 4.3, located in the north-eastern sector of Mt. Etna and recorded from 1 January 2000 to 31 May 2019. By integrating repeating earthquakes and ground deformation measured by GPS, we recognised distinct portions of the Pernicana Fault with different behaviors in terms of seismicity, repeating earthquakes and ground deformation, reflecting structural differences. The study of the recurrence behavior of repeating earthquakes showed lack of periodicity and low degree of regularity. This suggests that the occurrence of these earthquakes does not derive from a constant stressing rate acting on the fault, but rather from episodic triggering phenomena.

The significance of the 1971 flank eruption of Etna from volcanological and historic viewpoints

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The 1971 eruption represents a watershed in the recent history of Etna volcano. From a volcanological point of view, it marks an important change in the eruptive style and composition of the magma towards products richer in K, and led to the creation of a new summit crater: the Southeast Crater. It is no coincidence that, over the next fifty years, there would be an increase in the frequency of summit and lateral eruptions and associated output rate. From an historical viewpoint, the eruptive event of 1971 was the first important lateral eruption studied by the International Institute of Volcanology: the analysis of the scientific articles on this activity reveals a greater multidisciplinary content in the descriptions and explanations of volcanic activity. Particularly important were the collaborations of English and French research groups that, together with their Italian colleagues, succeeded in giving a complete picture of the eruption and describing the state of knowledge on the Sicilian volcano.

Field GPS data inversion to model Fiandaca tectonic lineament that caused seismic event on 26th December 2018 (Mt. Etna Volcano, Sicily)

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We present the analysis of geodetic monitoring of the tectonic lineaments along the eastern flank of MT Etna, affected by 2018 volcanic unrest. The intrusion of the hydrofracture responsible of the 24th and 25th December 2018 eruptive event, reactivated the Fiandaca fault causing 26th December 2018 seismic crisis. This uprising feeder dyke generated an E-W oriented remote stress field given rise a deformation along both east and west flank of Etna volcano. In particular the stress trajectory determines stress concentration along the main shear discontinuity given rise at an earthquake of Mw=4.9 and ML=4.8. The seismic event was followed by the reactivation of another tectonic structures on the eastern flank of the volcano such as the northern segment of the Pernicana Fault. The inversion of geodetic data, relating to the ground deformation of Fiandaca and Nizzeti fault segments, has been carried out through GAME tools to determine the fault segments source model of the 26th December 2018 seismic event. A source model, congruent with the geological, geometric and seismic characteristics of the analysed tectonic structures, has been defined through the implementation of Okada sources and the use of different GPS data inversion algorithms, in agreement with previous studies.

The 2011-2020 long-term sustained inflation at Long Valley Caldera: investigation of the magmatic system dynamics and evolution

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The Long Valley Caldera, California (USA), has been restless over the past few decades, experiencing seismic swarms and ground deformation episodes. The last inflationary phase began in late 2011, when a radially symmetric tumescence was detected coinciding with a large resurgent dome within the caldera. Since then, a continuous inflation with a quasi-steady rate of ~1.5 cm/yr has been observed within the caldera, concurrently with a series of earthquakes located on the southern side. In this study, we aim to investigate the nature and dynamics of the long-term unrest at Long Valley Caldera over the past decades. For this purpose, we consider a variety of geodetic datasets, including measurements from a dense network of continuous GPS stations, and high resolution Interferometric Synthetic Aperture Radar (InSAR) data from different satellite missions (i.e. TerraSAR-X, COSMOSkyMed and Sentinel-1). The time period covered by our data spans from late 2011 to the end of 2020. The use of a multi-sensor dataset allows to compensate the each technique limitations, leading to a reliable mapping of the evolving deformation pattern over the years. Data analysis highlights uplift velocities with peaks of ~2 cm/yr within the caldera and beyond its southern rim. Moreover, compared to the first half of the period of analysis (2011-2014), the area affected by high deformation rates is broader in the last years (2017-2020). Models based on geodetic observations are developed to constrain the deformation source at depth and to better interpret the observed signals. Our results reveal the presence of a spheroidal pressurized cavity at ~7 km depth below the resurgent dome area. The estimated volume variation of the source ranges in the order of 10e6 -10e7 m3/yr and is slightly decreasing in the last years, when lower velocities are measured. This study is motivated as a contribution to the understanding of this long-lived caldera unrest, for a more reliable hazard assessment.

Petrogenesis and geochemical characteristics of the Lar alkaline igneous complex, south-east of Iran

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This MsC thesis deals with a petrological and geochemical study of the Lar alkaline igneous complex located in the Sistan belt (NE, Iran). This complex is composed of intrusive and hypabyssal rocks of shoshonitic to ultrapotassic affinity showing different alkalinity and silica saturation degree. The most alkaline rocks include lamprophyres, nepheline-syenite and felsic dykes of phonolitic composition. On the other hand, silica-saturated and over-saturated rocks are represented by syenites and monzonites, respectively. Lamprophyres and nepheline-syenites show peculiar petrographic and geochemical features such as the presence of subsolidus unmixing textures involving nepheline and K-feldspar. The results of a thermodynamically constrained petrological model highlight a clear comagmatic link between the most alkaline rocks, whereas silica-saturated and oversaturated rocks lack the presence of parental magmas in the complex. The rocks of the Lar complex show geochemical features compatible with a subduction-related fingerprint. The former are characterized by higher LREE/HREE fractionation with respect to the latter that reflect a genesis by higher partial melting degree. The Sr-Nd-Pb isotopic composition is rather homogeneous suggesting a common mantle source for the Lar igneous rocks and that crustal contamination/assimilation processes are limited to the most differentiated products. A geochemical and isotopic based modelling suggests that the metasomatic agents that modified the mantle beneath the study area are mainly constituted by partial melts of altered oceanic crust and minor proportion by high- and low-carbonate sediments. These features are compatible with the geochemical variability observed in the Lar magmas, which show peculiar enrichments in LILE and depletion in LREE and Th. Magmas of the Lar igneous complex show similarities with those of the Neapolitan district of the Roman Magmatic Province, in particular with the post-leucititc phase.

SESSION 4 - MONITORING AND VOLCANIC RISKS

Conveners:
Andrea Bevilacqua and Silvia Massaro

Tephra fallout hazard assessment with uncertainty quantification: a case study from Cotopaxi and Guagua Pichincha volcanoes, Ecuador

INVITED KEYNOTE

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The use of numerical models aimed at producing probabilistic maps is becoming more and more a common practice for tephra fallout hazard assessment. However, it is important to complement such maps with a quantification of the major sources of aleatoric/epistemic uncertainties, to help stakeholders and decision-makers in taking informed decisions. In this contribution, we present an example of uncertainty quantification applied to a tephra fallout hazard assessment. The study is related to two volcanoes (Cotopaxi and Guagua Pichincha) threatening the capital city of Ecuador, Quito. Uncertainty was quantified with respect to three aspects: 1) the numerical model itself; 2) the probability of occurrences of different eruptive styles; 3) the range of variation of three eruptive input parameters (total fallout mass, eruption duration, average plume height). For point 1), the model used (which couples the plume model PLUME-MoM and the tephra dispersal model HYSPLIT) was tested in reproducing recent eruptions from South American volcanoes. This step allowed quantifying the difference between real (observed) and modelled values of several parameters, including mass loading, from which we derived coefficients of average model overestimation and underestimation. Concerning points 2) and 3), we performed an expert judgement (elicitation) session involving 20 experts of different countries and areas of expertise. This allowed deriving detailed uncertainty ranges that we used to i) sample the eruptive input parameters at each iteration during hazard map production; ii) linearly combine maps of different eruptive magnitude/style according to their relative probability of occurrence. The final products of this study are hazard maps of different formats and hazard curves for 10 sensitive sites in the city of Quito. Each of these maps/curves is presented as a set of three maps/curves ("lower", "mean" and "upper") which quantify the major sources of uncertainty.

Effective mitigation measures of lava flow hazards using optimized barriers configuration driven by numerical simulation

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Lava flows are a recurring and widespread form of volcanic activity threatening people and property around the world. In Italy, the mainly affected populations are those living on the slopes of Etna and Vesuvius. On Etna's flanks, 42 municipalities containing a population of 933.354, are at risk. On Vesuvius, if we consider only the current population living on lavas erupted in the last 400 years, they are a total of 337.500 people. The ongoing overcrowding around active volcanoes increases the potential risk and leads to a growing demand for faster and more accurate systems to safeguard the population. Attempts to reduce the hazard are rare, reflecting that in many cases this option is not possible. The building of artificial barriers has had some valid results, e.g. the walls erected on Hawaii (USA) and the earthen barriers built on Etna. These interventions contributed to slowing and limiting the expansion of lava flows and demonstrated how, in some cases, their advancement can be controlled. Even so, the problem of defining a methodology for the building of protection structures is very challenging and still open. Numerical modeling can provide a powerful tool for estimating the effect a barrier can have on lava flow paths. Thus, we developed an innovative methodology based on the Particle Swarm Optimization (PSO) algorithm to find the optimal configuration of artificial barriers, in terms of location and geometric features. The goal is to minimize the lava flow impact based on the spatial distribution of exposed elements, using the MAGFLOW numerical model to run the lava flow scenarios for each barrier configuration. Here, we describe the main characteristics of our algorithm: we define the search space, the target function, the constraints for barriers' placement, the way the particle system is initialized, and how the swarm evolves. Then, we provide a numerical example on Etna to illustrate the effectiveness of the proposed mitigation strategy.

Mapping of lava flows from the Mount Etna 2020-2021 paroxysmal events combining machine learning and satellite remote sensing techniques

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Measuring erupted volumes of lava flows is a crucial component of volcano monitoring, as it allows us to assess the hazard during an eruption. However, the locations, intensities, extents, and advancing of flows are difficult to observe with field methods because of the large extension and poor accessibility of the inundated areas. Satellite observations offer great promise to collect this information and allow the manifestations of the eruption to be followed once it has started. Satellite thermal remote sensing of hotspots related to effusive activity can provide many products suited to timing, locating, and tracking the radiant character of lava flows. Hotspots show the location and occurrence of eruptive events (vents). Discharge rate estimates may indicate the current intensity (effusion rate) and potential magnitude (volume). High spatial resolution multispectral satellite data can detect the flow front position (length) and extension of flows (area). Here, we propose a machine learning approach which relies on a variety of multispectral sensors, such as the Sentinel-1 SAR, the Sentinel-2 MSI and the Landsat-8 OLI/TIRS, to retrieve area coverage of lava flows, volume, and lava extrusion rates due to the South-East Crater 2020-2021 paroxysmal events on the summit area of Mount Etna. Firstly, we used machine learning techniques, including K-means algorithm (K-means), support vector machine (SVM), and decision trees to classify lava and background regions and estimate the relative spatial extensions. The use of specific spectral signatures for the classification, despite a manual threshold setting, makes this method very efficient. Secondly, we calculated the lava extrusion rates, i.e. the time-averaged discharge rate (TADR) derived from the radiative heat power measurements from satellite data. The algorithms are implemented in the Google Earth Engine (GEE) platform, which allows fast access and processing of satellite data from different missions.

Radiative heat power derived from Sentinel-3 SLSTR, MODIS and VIIRS during December 2020 – March 2021 lava fountains at Etna volcano

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Satellite thermal remote sensing is widely used to detect and quantify the radiative heat power produced by volcanic activity. Nowadays, a variety of multispectral satellites has sensors capable of measuring these infrared emissions and, as such, are regularly adopted for volcano monitoring from space. Here, we compared the fire radiative power (FRP) derived from the Sea and Land Surface Temperature Radiometer (SLSTR, onboard the Sentinel-3A and Sentinel-3B satellites), the Moderate Resolution Imaging Spectroradiometer (MODIS, onboard the Terra and Aqua satellites) and the Visible Infrared Imaging Radiometer Suite (VIIRS, onboard the Suomi National Polar-orbiting Partnership and NOAA Polar Orbiting Environmental satellites). The radiative power measurements (in Watt) obtained from these three sensors are related to the techniques used to detect the thermal anomalies, the methods implemented to derive the FRP values, and the characteristics of the sensor itself (as spatial resolution, scan angle, minimum detection limit, overpass time). A direct comparison between thermal anomalies detected by SLSTR, MODIS and VIIRS is difficult, because generally overpass time of the sensors is different, then we examined the overall level of thermal activity during a specific time interval, in order to evaluate the degree of similarity between the FRP values from these different sensors. In particular, we analyzed the SLSTR, MODIS and VIIRS measurements of the thermal flux observed at Mount Etna (Italy) during the long sequence of lava fountains that occurred between December 2020 and March 2021. Results obtained are discussed, highlighting the advantages and the limits of each sensor.

Applying pattern recognition techniques to infrasound signals at Mount Etna

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As an active volcano in close proximity to metropolitan regions like Catania, Mount Etna is a high risk factor for natural hazards. Therefore it requires constant monitoring which is performed by using a multidisciplinary approach. One of the parameters being recorded is infrasound. Possible volcanic sources for infrasound waves are for example Strombolian explosions or degassing processes. Therefore infrasound recordings are a vital tool in volcano monitoring. However, infrasound recordings are also affected by wind noise and feature a multitude of different waveform patterns that are difficult to interpret for the untrained human eye. For this reason we apply a pattern recognition technique called Self-Organizing maps (SOMs) to perform an automated classification of these waveforms patterns. We can validate the results on the basis of other results from the monitoring routine like infrasound event detection or visual recordings. SOMs provide an intuitive color coding to the results that enable an easy to perform assessment of patterns and the assignment of physical source mechanisms to the signals that are featured in the waveform – even to non experts.

Groundwater Level Variations in relation to Volcanic and Seismic Events. New Insights on Mt. Etna, Southern Italy

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In this preliminary study, the response of Etnean groundwater levels (GWL) to seismic and volcanic events between 2003 and 2007 was investigated. This period was characterised by frequent volcanic and seismic activity. Groundwater timeseries were filtered for the effect of meteoric contribution by employing the Cumulative Rainfall Departure (CRD) approach; these were then examined for correlations with volcanic and/or seismic events. Noteworthy variations in GWLs were observed in the proximity of eruptive episodes. These seemed to be consistent with the variation of other parameters such as ground deformation and SO_2 emissions previously investigated by other authors, and with the GWL fluctuations preceding the 2001–2002 seismic-volcanic crisis, detected by the Geochemical Monitoring System (GMS–2). Additionally, the variations observed before the phreatomagmatic explosion of January 12th, 2006, were the most evident among the whole examined period. With regard to this latter event, the GWL of wells to the S/SE sector of the volcano displayed a sudden and quasi-simultaneous lowering. These fluctuations commenced in November 2005 and were coincident with a moderate increase in the amplitude of volcanic tremor and mild inflation of the summit of the volcano, as recorded at permanent GPS stations. Less marked results have been obtained in relation to seismic events and it has not been viable to identify recurrent patterns of variation, mainly due to a low resolution of the available data. This work highlights how GWL variations might suggest, from days to months in advance, alterations to the geodynamic equilibrium of the Etnean region, providing evidence of the importance of groundwater monitoring and providing suggestions for future research. We envisage that this work will encourage the implementation of an efficient quantitative groundwater monitoring network which could reveal crucial information in the search for precursor signals.

Continuous monitoring of diffuse volcanic degassing by means of a microGC measurements at the summit of Teide volcano, Tenerife, Canary Islands

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The continuous monitoring of geophysical and geochemical parameters has always played a basic role in the study of complex natural systems. The changes in the chemical composition and in the flow of natural fluids reflect the mutations of equilibrium conditions and, therefore, if correctly interpreted, can give important indications on the state of activity together with the evolution of the monitored natural system. A project was developed that allowed to analyze diffuse volcanic degassing through the use of a CMS (Cromatography Monitoring System) which is an automatic chromatography system designed and built to allow a micro-gas chromatograph to analyze natural gas (He, Ne, O2, N2, CH4, CO, CO2, H2S, SO2 and CH4) with a temporal frequency fixed in the analytical method and a sequence controlled by the instrument management software. From the 2017 to the 2020, a CMS was installed on the Teide crater (3715 m). Aims of this approach was to create a system of continuous monitoring of diffuse volcanic degassing that acquire data every 1 hour in order to have timely and precise information on the variations of the chemistry in high temperature fluid like in a laboratory. During the acquisition period, variations in the chemical composition of the H2S and CO2 connected with precipitation (above all snow) were observed probably due to the rapid dissolution for the high solubility of this gases in water. A general system has also been hypothesized in which the precipitation interferes considerably with the concentration of the single species emitted. Furthermore, it was noted that during the winter periods, where the temperature fell well below zero, the quantity of gas analyzed decreased due to a freezing, distorting the analyzes. On the basis of the data obtained we will develop a system capable of reducing the problem of freezing and thus being able to have a complete database that can make us appreciate the endogenous and exogenous variations of the volcanic system.

GeoChem database: design and implementation of a data structure for geochemical data

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In a multidisciplinary approach to study the conduct of an active volcano, geochemical data represent very important elements to investigate the volcano behaviour and better understand different volcanic phenomena. Moreover, the technological development of the last decades has greatly increased the availability of geochemical data and measurements, so the scientific community has the need of new tools to store and to access them. In the framework of two European projects, Eurovolc and EPOS, an INGV team based in Catania and Palermo formed a working group with the goal to design and implement an integrated database for geochemical data, called "GeoChem". This structure will allow the design and development of a data structure compliant with the FAIR principle (Findability, Accessibility, Interoperability, Reusability). The development of a standard model for the database is based on three main requirements: i) to homogenize different types of geochemical samples; ii) to manage rock samples collected during petrological monitoring; iii) to manage volcanic and hydrothermal gas samples (i.e. steam condensate, dry gas sample, fumaroles). The goal is to implement a structure that can be used by the scientific community as a standard model for the representation of geochemical data of fluids and rocks, and allows an efficient discovery of data. The first phase of the process was dedicated to the analysis of the different domains of interest and the creation of metadata schemes that could best represent the information associated with the geochemical samples and analyses. The definition of the metadata scheme provides the common model for the geochemical data treatment and manages the collection of them. The model obtained was used for the implementation of the "Geochem" database. This data structure provides a good start point for the future works that may improve the data accessibility with the web services implementation, integrated into the EPOS platform.

The effect of three large Mw≥7.3 subduction earth-quakes (August-November 2012) on volcanic unrest in Central America

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"Was the volcanic eruption triggered by the earthquake?" The answer to this question usually is "maybe" or "a coincidence". A region like Central America, is an adequate area to find hints to answer this question because have the necessary ingredients: the frequent occurrence of large earthquakes (M5+) and dozens of active volcanoes. This research fo-cuses on whether the uncommon occurrence of three large earthquakes in the subduction zone of Central America, within a time span of ten weeks in 2012, promoted enhanced volcanic activity. The time window analyzed is from 2000 to 2019, which includes a total of 50 volcanic eruptions with a VEI≥2. Before the 2012 earthquakes, 22 eruptions oc-curred. The Monte Carlo statistical simulation method allowed to demonstrate that this increase in the number of volcanic eruptions after the three large earthquakes of 2012 it is not a temporal coincidence. We analyzed the characteristics of each earthquake and described how they could disturb the volcanic systems. Although Central America hosts 24 volcanoes with historical eruptions, only 11 of them erupted after the 2012 earthquakes. Why did only these volcanoes erupt? To answer this question, we calculated the dynamic and static stress in each volcano and the level of volcanic unrest (the change in volcanic activity beyond background behavior to worrisome levels) prior to the earthquakes. We found that volcanoes in a unrest stage before the earthquakes but, without experiencing explo-sive eruptions before, erupted after receiving the seismic shocks. This fact suggests that the earthquakes by themselves did not transfer enough energy to generate the volcanic eruptions when volcanoes were not ready to erupt. However, earthquakes could promote volcanic eruptions when volcanoes were already at unrest. This research offers a tool for forecasting volcanic activity when a large earthquake hits a region, if the volcanic activi-ty is previously monitored.

Multidisciplinary study of the dynamics along the southern rift and Pernicana fault system and relations with the Etna eruptive activity during the last 30 years

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The complex interaction between regional stress, gravity forces and dike-induced rifting of Mount Etna, have a role in the eastward movement of the Mt. Etna eastern flank. In that context the Pernicana and the southern fracture system (Trecastagni/1989 fracture system) identify the northern and southern boundaries of the unstable sector. The eastern segment of Pernicana fault (strinking NE-SW) show aseismic creep and left-lateral displacement. The 1989 fracture system probably is in connection with the Trecastagni Fault (southern rift) that show right-lateral movement and creep phenomena. We investigate both fracture systems with multi-disciplinary approach terrestrial (levelling, extensometers) and satellite (satellite, GPS, InSAR) ground deformation data. Avaiable data on levelling, extensometers, GPS and InSAR along Pernicana and southern fault system show differents vertical displace along both structure from some to several millimeters/y and grow on the trace fault. In general the subsidence increase toward east. Also the 1989 fracture system shows important deformations: in particular, thanks to the discrete and continuous INGV monitoring networks, we could investigate the fracture dynamics through 30 years of ground deformation data and find the connections with the volcanic activity. The greatest deformations were recorded in three particular moments for Mt. Etna: during the 1989 eruption (EDM, GPS and levelling showed deformation measurements variations of tens centimeters close to the fracture), during the 2001 eruption (a network of extensometers evidenced activation intrusion measuring several centimeters of left lateral slip), during the 2018 eruption (InSAR data). The dynamics of the 1989 fracture, together with the tectonic structures of the lower SE flank and the Pernicana Fault play an important role in the dynamics of the flank and the distribution of deformation in that flank. They also represent a potential danger for the population.

Monitoring volcanic thermal emission using VIIRS

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Volcanic activity is always accompanied by the emission of heat into the atmosphere. The aim of this work is to study the infrared data provided by the Visible Infrared Imaging Radiometer Suite (VIIRS) in order to quantify this heat and to ensure data continuity with the operational volcano hot spot detection systems, currently based on Moderate Resolution Imaging Spectroradiometer (MODIS) data. For this purpose, VIIRS data acquired during the 2019 Stromboli's eruption were processed using the Middle Infrared Observation of Volcanic Activity (MIROVA) algorithm, and compared with MODIS data. The results obtained show an excellent correlation between VRP values of VIIRS and MODIS and a comparable trend of the total energy radiated by the eruption. Moreover, the improved spatial resolution of VIIRS results into a higher sensitivity to small thermal anomalies and allows to detect more alerts than MODIS. These results confirm the great potential of VIIRS to complement MODIS data for volcano thermal monitoring, and possibly to replace them, in view of a future end of NASA's EOS missions (Terra and Aqua).

Long-range infrasound detection of explosive volcanic activity

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Explosive volcanoes are efficient sources of infrasound (low frequency sound), that might be used for detecting, locating and quantifying activity in real-time. Infrasound analysis of explosive eruptions is not limited to local (250 km), thus opening new perspective for volcano monitoring. Here we investigate the potential of the infrasound network of the International Monitoring System (IMS) of the Comprehensive nuclear Test Ban Treaty Organization (CTBTO) to detect volcanic eruptions at large distances. We focus on 10 years of data (2010-2019) recorded by two stations (I18DK in Greenland and I22FR in New Caledonia). Volcano infrasound is identified by applying an azimuthal filter to infrasound detections, and once propagation effect are considered, we calculate the Infrasound Parameter (IP) for selected volcanoes. We show how this approach allowed to detect and analyse the 2010 Eyjafjallajökull and 2011 Grimsvotn eruption in Iceland, using the I18DK array in Greenland (at 2300km), and the persistent low energy explosive activity of volcano Yasur, using data from the I22FR array in New Caledonia (at 400 km). During favourable propagation conditions, volcanic activity is monitored almost in real-time, and able to detect variations of activity over short (minutes-hours) time scales, that are below satellite observations and comparable to local geophysical monitoring. Despite the efficiency of long (>250 km) range infrasound monitoring varies seasonally with propagation conditions of infrasound in the atmosphere, it can complete satellite observation global monitoring of volcanic eruption and could be used as a warning and notification system.

A GIS-based approach to evaluate the hazard by lava flow invasion at Mount Etna volcano (Sicily, Italy)

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Lava flows are among the most impressive volcanic phenomena that Mt. Etna may offer. Yet the ability of lavas to spread across urban and rural areas, burning and burying buildings, infrastructures and fields, results in high volcanic hazard and risk, mostly because of the high density of inhabitants living around the volcano. At Etna, effusive eruptions occurring from vents and fractures located at low altitude on the volcano flanks, are those more prone to produce dangerous scenarios because of their proximity with residential areas. In this study, we propose a GIS-based approach for evaluating the hazard associated to future lava flow invasion in the area of Mt. Etna. A GIS-based approach has been adopted in order to map historic lava flows occurring over the last 2,5 ky based on the historical cartography available. The QGIS software has been used to create two main shapefiles related to the areal distribution of lavas and their associated vents. Characteristic parameters of each lava flow, such as the eruption date, duration, length, areal distribution, and position of the vent, are listed and included in the database. As a second step, the entire Etnean area has been divided in twelve minor domains, which are distinct one from each other on the basis of their average altitude and geographic location. Such partition will allow proper assessment of the spatial and temporal distribution of vents and lava flows, which finally will serve to discriminate between spatial domains characterized by different hazard.

MISARA: Matlab Interface for Seismo-acoustic ARray Analysis

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Volcanoes exhibit a large variety of seismo-acoustic signals, whose characteristics often provide important clues on the ongoing processes. The investigation of these signals, therefore, plays a key role in the study of volcano dynamics, but it requires specific techniques of analysis and/or networks geometries due to their unique features. The continuous monitoring of the seismo-acoustic signals is also very important to surveillance purposes, but it rapidly leads to the accumulation of a large volume of data, thus making it crucial the rapid extraction of the parameters of interested and the automatization of the processes. For these purposes, we present an open-source MATLAB GUI (Graphical User Interface), named MISARA (Matlab Interface for Seismo-acoustic ARray Analysis). MISARA is mainly based on the combination of various techniques of analysis, including spectral, amplitude, correlation, polarization and array techniques. It is designed hence to support the visualization, characterization, detection and localization of different volcano seismo-acoustic signals. Its intuitive modular structure facilitates the immediate inspection of the results. The integration of automatic and active steps improves also the efficiency of the data processing and reduces the user efforts. Essentials of MISARA are tested on the seismic data recorded at Etna Volcano (Italy) in 2010 and 2011, during different states of the volcanic activity. MISARA is intended to be applied for academic/research uses, for temporary surveys, or during routine analysis at volcanological observatories.

Seismic Tomography of Southern Tyrrhenian

Giuseppe Pucciarelli*

Indipendent Researcher

The topic of my work is a seismic tomography which has as object the investigation of Southern Tyrrhenian. This tomography has been obtained by means of inversion of teleseismic data to investigate subduction zones in the Southern Tyrrhenian oceanic back-arc basin. The subducting lithosphere has been mostly consumed along the Tyrrhenian-Apennine system with the exception of the Calabrian arc sector. Teleseismic inversion could provide a good resolution to depth of 500-600 km, whereas previous local tomographies of Southern Tyrrhenian show results to depth of 250-300 km. The adopted database consists of 1929 teleseisms recorded in period 1990-2012 by 122 southern Italian seismic station directly connected to ISC (International Seismological Centre). The software FMTT was employed for the inversion of these arrival times. I have implemented a grid of 0-500 km in depth, 7°E-20°E in longitude and 35°-48° in latitude, with a grid spacing of 50 km in depth, 0.8 degrees in longitude and 0.4 degrees in latitude. I have made 10 horizontal sections of final model from 50 km of depth to 500 km of depth, with an interval of 50 km of depth from each other. I have made 8 vertical sections, 4 NS vertical sections at fixed longitude and 4 WE vertical sections at fixed latitude. Finally, I have made 3 transversal sections. Summarising, the horizontal sections show an evolution of the high velocity body that represents the Ionian slab. It is visible both at depth of 50 km and at depth of 100 km, beneath the Calabrian arc and extends to northern Sicily beneath the Aeolian arc with a maximum of 0.6-0.8 km/s. At depth of 250 km, the tomography evidences a sort of "transition" due to the absence of the Southern Tyrrhenian HVA and the occurrence of a low velocity region with maximum of -0.5 km/s scattered between the Aeolian Islands and Calabria. The presence of this "window slab" could be interpreted as a tear in which unperturbed mantle insert itself.

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