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Cover | *In copertina* Catania after the 1669 euption (Anonymous, ca 1687)

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S1. GEODYNAMICS AND TECTONICS CONTROLLING VOLCANIC SYSTEMS

Conveners:
Luciano Scarfì (INGV-OE), Giovanni Barreca (UniCt)

Fissural vs. punctual monogenetic volcanism: first evidence of continental breakup in the Northern Main Ethiopian Rift

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Decoupling between long-term geological processes and human life does not allow scientists to have direct connection with timescales of phenomena related to plate tectonics. This is the reason why, albeit widely accepted all over the world, plate tectonics is still a model and not an axiom of Earth Sciences. Scientists watch only a snapshot of a million-years-scaled sequence of events. This is the case of mid-ocean ridges, which are the final result of continental drifting and magma output at divergent plate boundaries lasting ten-to-hundreds of millions of years. In addition to the temporal issue, in most cases, the transition from continental rifting to seafloor spreading is difficult to be studied, as most of these systems are submarine. The East African Rift (EAR) offers the unique opportunity to have a glance on such long-time processes, as rifting is progressively propagating from the Afar triple junction to the south, through the Main Ethiopian Rift (MER) and the Kenya Rift.
Volcanism along MER extends for thousands of kilometers, with a decreasing frequency from the Afar depression toward its southern part, mainly due to an increasing rigid behavior of lithosphere and, hence, a higher difficulty for magmas to reach the surface. Volcanic and tectonic manifestations in the Northern Main Ethiopian Rift (NMER) are spatially clustered into four *én-échelon* magmato-tectonic segments, each one characterized by the occurrence of a central silicic volcano in the intermediate part and of tens-to-hundreds of basaltic monogenetic scoria cones (MSC) and associated minor lava flows.
A new geological survey and sampling of volcanic products in the Northern Main Ethiopian Rift (NMER) led us to discover the first rifting episode in the area, which occurred around the 1810 CE across the Fantale and Boseti volcanoes. The rifting episode developed through a system of *én-échelon* eruptive fissures (EF) distributed over 7-11 km and with orientation comparable to the Wonji Fault Belt. The EF basaltic lavas preserve the same petrographic and geochemical characteristics throughout the NMER. Indeed, they are almost aphyric and bear the typical high-Ti signature (TiO_2 > 3.5 wt.%) of other volcanic products in the area. Central volcanoes and EF are at the center of each tectono-magmatic segment, whereas tens-to-hundreds monogenetic scoria cones (MSC) populate the external portions of the NMER. MSC basaltic tephra are plagioclase-dominated, with a total content of phenocrysts around 30 vol.%. PRIMELT3 and Rhyolite-MELTS simulations highlighted that both EF and MSC volcanic products have the same parental magma. After storage at the Moho level (19-23 km of depth), EF and MSC magmas encountered, however, distinct differentiation and ascent dynamics. EF magmas underwent deep fractionation of mafic phases and reached rapidly the surface, conditions that lead us to infer a mechanism of magma-assisted rifting for these episodes. Conversely, after deep fractionation of mafic phases, MSC magmas have evidence of further storage and crystallization histories at 10-14 km of depth. From this storage zone, single magma batches can rise either through already existing fractures/faults or newly formed, deep faults associated to the Wonji Fault Belt.

The integration of all our data also suggests that Fantale and Kone volcanoes do not have an active magmatic plumbing system: the recent EF events have been able to intrude their central edifice, but they do not show any evidence of mixing or mingling with more evolved magmas. Conversely, their plumbing systems were able to buffer the ascent of the single batches of MSC, as evidenced by the complete absence of scoria cones within a radius of 10-12 km from the center of calderas of central volcanoes.
Our model envisages that central volcanoes and eruptive fissures, originated through rifting episodes, take place in portions of tectono-magmatic segments characterized by major extension, whereas MSC in those segments with lower rates. Within this framework, variable trends of the differentiation and ascent dynamics primarily depend on the increasing extensional rate through time. Our findings reveal that the process of continental break-up in the NMER is already ongoing, which means that the process can no longer be considered incipient and other diking/rifting events are especially expected in the central area of each tectono-magmatic segment.

S1.1 - Presentazione orale

The volcano-tectonic activity of the Ririba rift and the evolution of rifting in South Ethiopia

Zara Franceschini[1,2], Raffaello Cioni[2,3], Giacomo Corti[3,5], Federico Sani[2], Stéphane Scaillet[4], Ilaria Isola[5], Francesco Mazzarini[5], Florian Duval[4], Asfaw Erbello[6], Ameha Muluneh[7], Sascha Brune[8]

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The relationships between volcanic activity and tectonics at the southernmost termination of the Main Ethiopian Rift (MER), East Africa, are presented and discussed to define the evolution of rifting. We provide new constraints on the timing, evolution and characteristics of the poorly documented volcanic activity of the Mega and Dilo-Dukana volcanic fields (VF), near the Kenya-Ethiopia border. The new data delineate the occurrence of two distinct groups of volcanic rocks: subalkaline basalts, observed only in the Dilo-Dukana VF, forming a lava basement during Pliocene then faulted during a significant rifting phase; alkaline basalts, occurring in the two volcanic fields as pyroclastic products and lava flows from scattered Quaternary monogenetic edifices, which postdated the rifting phase and sealed the rift-related faults. $^{40}Ar/^{39}Ar$ dating constrain the emplacement time of the large basal lava plateau to ~3.7 Ma, whereas the youngest volcanic activity characterizing the two areas dates back to 134 ka for Dilo-Dukana, to as recent as the Holocene for Mega VF. We investigated the Quaternary volcanic activity of the study area by characterizing the different types of volcanoes, their morphology and spatial distribution. In contrast with other sectors of the rift, we find that this recent volcanism developed along tectonic lineaments independent from those of the rift: our analysis indicates no direct relations between the Pliocene, roughly N-S-trending major boundary faults of the Ririba rift and the NE-SW-oriented structures feeding the Quaternary volcanic activity. We speculate that this change in structural trend may be the expression of (1) inherited crustal structures affecting the distribution of the recent volcanic vents, and (2) a local stress field controlled by differences in crustal thickness, following a major episode of reorganization of extensional structures in the region due to rift propagation and abandonment.

S1.2 - Presentazione orale

Mantle flow and crustal collision: is the prelude to the end of volcanism at Mt. Etna?

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Mt. Etna in southern Italy is one of the most studied volcanoes in the world and continuous monitoring for hazard aims over the last 40 years have allowed to compile a huge amount of data regarding the deformation affecting the volcano, lava composition, lava flows mapping etc. Despite the enormous volume of literature resulting from data interpretation, to date Mt. Etna has been seen as a stand-alone volcanic system and its evolution has never been framed in the wider geodynamic context where the volcano is situated. In this work, we have investigated the entire geological history of the volcano, reinterpreting some significant changes in magma composition and in the eruptive style (among many others) as premonitory signals of volcano decline. This new interpretation is primarily based on the reconstruction of the lithospheric system and on the current stress-state beneath and around the volcano, respectively. Geo-structural interpretation on available tomographic sections crossing Eastern Sicily clearly indicate that trench-parallel breakoff of the previously subducted Ionian slab has occurred north of the volcano. This slab originally separated the Aeolian magmatic province (island-arc) from that of Etna (plume-related), two distinct magmatic systems fed by melts coming from different mantle sources. Following the simple assumption that if a slab retreats it must either be compensated or alternatively pushed by the supra-subduction mantle wedge, we argue that the opening of a gateway in the descending slab has triggered a flux towards the south of the warmer and lighter fore-arc mantle. According to our interpretation, mantle mobilization is having a twofold consequence: i) magmatic source mixing (island-arc vs. plume) and ii) the inception of a collisional stage beneath Mt. Etna. The combined effect of the two processes are here retained responsible for the increase in explosiveness and of the total number of lateral eruptions registered during the last thousand years. All the analyzed data (i.e. geochemistry, deformation field, seismicity, strain rate, inflation process and so on), seem to converge toward the proposed geodynamic model in which a newly-settled, deep-seated crustal contraction is having a strong impact on the life of the volcano, representing a highly-unfavorable scenario for volcanism continuation in the area. Depleted mantle replaced by a primary mantle beneath the (today inactive) Alicudi and Filicudi volcanic islands in the western Aeolian Arc, provide constraints for mantle mobilization after slab detachment. Thrusting activation in the crust overlying a travelling mantle and mantle mobilization after slab detaching are considered here to be the main processes responsible for volcanism evolution/cessation along and nearby subduction systems.

S1.3 - Presentazione orale

Volcano-tectonic setting of Mt. Etna offshore

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Mt. Etna lies along the Ionian coast of Sicily in a complex geodynamic setting, where the front of the African vs European plates' collisional belt overlaps the Hyblean continental foreland crustal block. The Mt. Etna area is affected by strike-slip tectonics, characterized by different shear zones [Firetto Carlino et al., 2019]. Their activity and mutual interaction led to the formation of local releasing zones, which favored the emplacement of deep magmatic intrusive bodies and Plio-Quaternary scattered volcanics. Transtensive structures were lately inverted, as evidenced by push-up structures identified offshore the SE portion of the volcano, resulting in the overall time-space migration of the volcanic centres. Strike-slip tectonics locally led to the formation of shallow neotectonic features along the eastern flank of the volcano (both on- and offshore), controlling the eastward gravitational sliding and producing important seismicity.
The available dataset used for this work is composed of a dense set of high-resolution multi-channel seismic reflection, magnetic and gravity data, acquired offshore Mt. Etna during 2014 within the TOMO-ETNA experiment [Coltelli et al., 2016]. The dataset is integrated with high-resolution bathymetric data, ROV images, sea-floor samples and other single- and multi-channel seismic reflection profiles [Chiocci et al., 2011; Mazzarini et al., 2017].
The main goals of this work are to further improve the understanding of the relationship between tectonics and volcanism, and to better characterize the geodynamic asset of Mt. Etna region, specifically focusing on the northern offshore region, which needs to be better detailed. Bathymetric and seismic reflection data revealed that the continental margin offshore Mt. Etna presents a large and uneven bulge, characterized by horsts and grabens, pertaining to the Hyblean foreland domain. These structures are bounded by NNW-SSE and NE-SW lineaments, related to the Malta Escarpment and the foreland flexure beneath the thrust belt, respectively. To the south, the bulge is characterized by the Timpe Plateau, a rhombohedral Hyblean horst, which shows no evidence of alloctonous nappes related to the Sicilian Apenninic-Maghrebian fold-and-thrust belt. It is strongly affected by strike-slip tectonics, highlighted by a large, wedge-shaped transpressive push-up, developing along the WNW-ESE trending Aci Trezza Lineament [Firetto Carlino et al., 2019].
The northern portion of the bulge is indeed characterized by the Riposto Ridge (RR), a roughly E-W trending morpho-structural high, extending from the Fiumefreddo-Torre Archirafi coast down to the bathyal plain (1800 m bsl). RR flanks are strongly eroded by a dense network of gullies and canyons, suggesting a long-lasting erosive activity.
The RR shows a high degree of deformation, due to local push-up-like morpho-structures, which suggest the occurrence of strike-slip tectonics. This deformation may also favored diffuse gravitational instability observed especially along the deepest portion of RR [Argnani et al., 2013]. In addiction, we found evidence of alloctonous nappes of fold-and-thrust-belt in the RR area.
The shallow extent of the RR is dissected by a NE-SW trending extensional fault system, representing the offshore continuation of the coastal faults, which also influence the seaward gravitational sliding of the lower Etna eastern flank. This fault system seems to control the sinuous path of the Riposto Canyon, which deeply cut the nearshore portion of the RR. It

produces sub-vertical scarps offsetting the seafloor, associated with scattered and locally well-developed volcanic bodies, which are the product of local eruptions. Submarine volcanics are interbedded within the Plio-Quaternary succession, as observed on seismic profiles, or exposed at the seafloor, where they were also sampled. Magnetic and gravity data strongly validate the reliability of the seismic interpretation. In particular, the reduced-To-the-Pole map displays very high-frequency RTP anomalies, related to shallow intrusive bodies on the nearshore portions of the RR [Cavallaro et al., 2016].

We suggest that strike-slip tectonics may have played an important role in driving volcanism also in the RR area.

S1.4 - Presentazione orale

Mapping the b-value at Etna volcano using the 2005-2018 earthquake catalogue

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The cumulative number of earthquakes and related magnitudes, occurring within a certain time interval, are arranged along a log-linear trend, following the Gutenberg and Richter Frequency-Magnitude-Distribution (FMD). The slope of the straight line which better fits the FMD is defined as b-value and describes the average size distribution of earthquakes.
b-value is typically equal to nearly one on a global scale; temporal and spatial variation of b has shown to document changes in the relevant stress conditions [e.g. Gulia and Wiemer, 2019 and references therein], highlighting crustal regions where the production of small earthquakes is statistically higher or lower than the average. Thus, crustal regions showing b-values much less than one are characterized by statistically reduced numbers of small-energy seismic events, reflecting possible asperities or stress concentration zones [Wiemer and Wyss, 1997], perhaps linked to variations in frictional properties along a fault. Instead, values of b significantly higher than one, generally characterizing specific regions in volcanic areas, are thought to reflect the local increasing density of smaller faults and cracks around active magma chambers and fluid-filled fractures at depth [Murru et al., 2007], resulting in the reduction in shear strength on cracks and fault surfaces, with the consequent preferential production of small seismic events.
Since 2005, the number of stations of the seismic network of eastern Sicily significantly increased, and three-component broadband seismometers, with digital recording systems, were also employed; this resulted in improved accuracy in earthquake localization and in the use of the local Magnitude for earthquake-size estimation. The above characteristics strengthen the reliability of b-value calculation since the seismic catalogue after 2005 is certainly characterized by a lower and more accurate completeness Magnitude.
We analyzed the temporal and spatial variation of b in the Etna area, using a seismic catalogue which includes nearly 10.000 earthquakes occurred between 2005 and 2018. The aim of the study is to highlight high b-value regions, which may reflect the occurrence of active magma storages at depth, and to investigate eventual precursor of volcanic and seismic activity by analyzing the temporal variation of b.

S1.5 - Presentazione orale

The Presenzano dike (Roccamonfina volcanic area, southern Italy): evidence of tectonic control on dike emplacement and interaction with the carbonate host-rock

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In this study we performed a structural survey on fractures, faults, and dikes. The latter structures are hosted in Mesozoic carbonates exposed in the Presenzano quarry and Pleistocene breccias near Presenzano town, northeast to the Roccamonfina volcano. In order to carry out petrographic and chemical analyses, we collected several samples, in the Presenzano quarry, along a transect from the host-rock to dike core. Structural data indicate that the dike is characterized by a segmented contact with the carbonates with a dominant NE-SW (i.e., Anti-Appeninic trend) and a secondary N-S direction. The dike is further dislocated by N-S and E-W trending faults, with transtensional and normal kinematics, respectively. The thickness of main dike ranges between 18 and 25 m. Minor dikes are few meters to tens of centimeters thick. The contact between the main dike and the host-rock displays a large thermo-metamorphic aureole defined by recrystallized limestone with a foam structure (skarn). Petrographic analyses of dike samples, collected along the transect, show variations in structures and fabric with a homogeneous magmatic assemblage consisting of large crystals of Clinopiroxene (Aeg-Aug to Di-Hd), Plagioclase (An 35-45%) with Leucite, Biotite, and oxides in the groundmass. Moreover, moving from the dike core to the rim, we observed an increase of the Ca and Mg content and a decrease in the crystals preferred orientation. The preliminary results suggest a contribution of processes of decarbonatation and carbonate assimilation during the dike emplacement, which likely occurred along a preexisting damage zone in the late stage of the Roccamonfina activity.

S1.6 - Presentazione orale

Different geochemical and isotopic footprints of magmas erupted in the rear arc zone of Ecuador characterized by slab segmentation: insights from El Reventador, Sumaco and Cerro Negro volcanoes

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Major-trace elements and Sr-Nd-Pb-B isotopes were measured in samples from a collection of rocks erupted by El Reventador, Sumaco and Cerro Negro volcanoes, located in the rear-arc zone of the Ecuadorian Andes (Northern Volcanic Zone - NVZ). Despite being located at the same distance from the trench (~350 km), and only ~30 km far from each other, magmas erupted from these three volcanoes (N-S aligned), exhibit different major-trace element compositions and isotopic signatures.

The products of El Reventador active volcano (the northernmost one) are mainly represented by porphyritic lavas, ranging from basalt to rhyolite, with basaltic-andesite and andesite being the most abundant. They belong to the medium-K to high-K calc-alkaline series, characterized by higher $^{87}Sr/^{86}Sr$ and lower 143Nd/144Nd with respect to those of Sumaco (the southernmost one) but well within the Sr-Nd isotopic range of the Ecuadorian NVZ [Ancellin et al., 2017; Gutscher et al., 1999].

Extrusives of the active to semi-active Sumaco volcano consist of high-K alkaline, markedly SiO_2-undersaturated (often with modal feldspathoids) rocks ranging from basanite to phonolite. The overall geochemistry of the samples is very different from that observed for most volcanoes of the NVZ. The narrow range of Sr-Nd isotope compositions and the major and trace elements distributions indicate that, besides relatively low-degree of partial melting of the mantle source, the Sumaco magmas differentiated mainly through crystal fractionation with probably small contribution of crustal contamination, in accordance with the thick (>50 km) and old (Precambrian) continental lithosphere beneath the volcanic edifice.

Cerro Negro (a semi-dormant to dormant volcano), geographically located between the Sumaco and El Reventador is characterized by trachybasalts to trachydacites of the high-K calc-alkaline series and show geochemical features which partially overlap those of the other two volcanoes. The Sr-Nd isotope ratios show a quite large variation range (i.e. $^{87}Sr/^{86}Sr$ =0.7053-0.7070 and $^{143}Nd/^{144}Nd$ = 0.5124-0.5128) and an anomalous negative correlation.

Although El Reventador, Cerro Negro and Sumaco volcanic products show the typical Nb-Ta-Ti negative anomaly as the result of the common subduction-related environment, they exhibit, completely different modal mineralogy and trace element geochemistry. Small enrichment in incompatible trace elements with silica increase are typical of El Reventador lavas, especially for LREE (e.g. La, Ce). By contrast, the Sumaco lavas are strongly enriched in all incompatible elements and show very low values of LILE/HFSE and LILE/REE ratios (e.g. Ba/Nb and Ba/La). Products of Cerro Negro distinctly cover the compositional gap which is present between El Reventador and Sumaco for LREEs abundances and LILE/HFSE and LILE/REE ratios.

The three investigated Ecuadorian volcanoes grew upon the same basement rocks and over a mantle wedge having the same characters. Different geochemical and isotopic footprints might be therefore driven by the presence of the southern limit of the flat-slab Carnegie ridge (i.e. the Grijalva Fault Zone) in the southernmost area of the three investigated volcanoes (close to Sumaco) that can produce a lithosphere tearing between the younger (Nazca) and the older (Farallon) subducting lithospheric plate. In fact, differences in the geometry and/or age of the subducted slab may be responsible for heterogeneous kind of fluids and melts which can induce different extent of metasomatism in the mantle wedge where the basic magmas of the active continental margin originate. The Sumaco basic magmas are consistent with very low degrees of partial melting due to the metasomatism of a supra-slab mantle wedge by small amounts of 11B-depleted fluids released from subducted altered oceanic crust and sediments. In contrast, under the El Reventador volcano a carbonatic sediment component (with low 206Pb/204Pb and high δ11B) is invoked as significant agent of mantle wedge metasomatism. Cerro Negro (Pb and B isotopic analyses are on-going) which is just located in a transitional environment could represent the -trait d'union- between the two other volcanoes.

S1.7 - Poster

Geodetic and seismic moment-rates comparison on Sicily Channel (Italy)

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Seismic and geodetic moment-rates comparison can reveal regions with unexpected potential seismic hazard. Sicily Channel represents a region with a potentially moderate seismic hazard, due to the occurrence, in the recent past, of volcanic eruptions sometimes accompanied by significant seismic swarms. By using both historical and instrumental seismic catalogs as well as an update geodetic velocity field we performed such a comparison for the Sicily Channel area.
The Sicily Channel is part of the Pelagian block, a continental crustal portion of the African continental margin which extends from Tunisia to eastern Sicily and is separated from the Ionian Basin by Hyblean-Maltese Escarpment Fault System. The evolution of the Pelagian block has been strongly influenced by the complex interaction between the Nubia and Eurasian plates. Since late Miocene, and mostly during the Pliocene, the Sicily Channel has been affected by extensional tectonic processes which leaded to the development of tectonic depressions (e.g. Pantelleria, Linosa and Malta troughs). These depressions have been interpreted as large and discrete pull-apart basins involving deep crustal levels that developed in front of the Africa-Eurasia collisional belt within a large dextral wrench zone.
To investigate the seismic characteristics of the Sicily Channel, we considered the instrumental seismicity using earthquake data recorded during the period 1983-2018 by the INGV permanent seismic network [http://iside.rm.ingv.it]. We selected a NW-SE oriented sector with approximate coordinates of vertices: Lat. 37.00 - Long. 10.00, Lat. 38.60 - Long. 11.55, Lat. 35.68 - Long. 16.60, Lat. 33.73 - Long. 14.91. The earthquake distribution highlights that seismicity is scant and mainly concentrated along a broad N-S elongated tectonic lineament, extending from Lampedusa Island to the Graham Bank, which marks the segmentation of the extensional Sicily Channel system into two separate branches.
We calculated the seismic moment-rate according to the [Hyndman and Weichert, 1983] formulation, which was obtained by integrating the cumulative truncated Gutenberg-Richter distribution up to the maximum magnitude value that could occur within our study zone. As the largest earthquake striking the investigated area had an estimated magnitude equal to 5.1, following [Kijko and Graham, 1998] and [Kijko and Singh, 2011], we assumed a value of 5.6 as possible maximum magnitude. Estimated seismic moment-rate is $3.32 \cdot 10^{16}$ Nm/yr.
All continuous GPS stations installed across the Sicily Channel as well as the ones on southern Sicilian onshore (2001.0-2018.0 time interval) have been processed by using the GAMIT/GLOBK software packages. After estimating the GPS velocities (referred to a fixed Eurasian reference frame), we computed the geodetic horizontal strain-rate tensor on a regular 0.25° x 0.25° grid. The western sector is dominated by a prevailing contractional field with the minimum deformation axes having a W-E attitude in area comprises between Pantelleria and SW Sicily, and a WNW-ESE attitude in area comprises between Pantelleria and Lampedusa. The eastern sector is dominated by a prevailing extensional field with the maximum deformation axes aligned to the NE-SW direction, coupled with a minor contraction with the minimum deformation axes having a NW-SE attitude. For the area of study, we calculated the geodetic moment-rate

according to the [Savage and Simpson, 1997] formulation, assuming values of $3.3 \cdot 10^{10}$ N/m^2 and 20 km for rocks shear modulus and seismogenic thickness, respectively. Estimated geodetic moment-rate is $8.95 \cdot 10^{17}$ Nm/yr.
The morphotectonic domains over the study area have been analyzed through interpretation of a set of SPARKER seismic data acquired by IGM (now ISMAR-Bo) in the Sicily Channel during the 70's. These data, available only in hard copies, have been digitized, processed and geo-referenced using the open-source software Seisprho. Interpretation of these data allowed to identify first order morphotectonic domains and their structural boundaries.
Basin depocenters mark first order structural boundaries between different morphostructural domains. However, seismic reflection data suggest that these structural depressions are not tectonically active, since recent sediment filling the basin depocenter does not show evidence of incipient deformations, while horizontally onlapping the acoustic basement. Seismic reflection profiles show evidences of active deformation along a N-S trending corridor, where a diffuse and complex pattern of transtensional and transpressional deformation is presently affecting the sedimentary sequence up to the seafloor. These evidences suggest that fully seismic deformation occurs mainly along narrow active tectonic areas which are unable to account for the total deformation budget measured geodetically.

S1.8 - Poster

Moment tensor solutions at Mt. Etna volcano

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In a volcano, seismic events can be related to multiple processes, such as brittle fracture, fluid flow, mass transport and volumetric changes. Therefore, seismic signal analysis and an adequate characterization of the seismic source is usually performed to monitor its activity and to provide a reliable understanding of its internal processes.
The earthquake source can be successfully studied through the seismic moment tensor computation, which also provides additional hints about non-double couple components of the acting forces. However, this kind of measurement in a volcanic environment is a difficult task due to the complexities of the structural model, to the wave propagation effects and to the presence of noise in the data.
On December 24, 2018 an intense seismic sequence preceded and accompanied the beginning of a flank eruption at Mt. Etna volcano (Italy). The relevant seismicity and the large ground deformation [Bonforte et al., 2019] are a clear evidence of the impressive dynamics that characterized the volcano during this last eruption which, despite the low volume of magma poured out, can be considered one of the most important ones of the last 30 years.
In this study, we analysed the Etnean seismicity and calculated the complete moment tensor of a selection of earthquakes recorded by the broad-band network of INGV-CT during the last eruption, with the aim of providing new insights into the eruption dynamics. In particular, we investigated the source mechanisms and the possible involvement of magmatic fluids.

S1.9 - Poster

Monitoring of post-seismic deformation:
The Fiandaca-Pennisi shear-zone (Mt. Etna, Sicily)

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On 26th December 2018 the eastern slope of the Mt. Etna volcano was affected by a seismic sequence with maximum magnitude of 4.8 located at 1,5 km NE from the village of Lavinaio (Sicily) at a depth less than 1 km [Gruppo Analisi Dati Sismici, 2019]. The Fiandaca Pennisi fault, one of the most seismically active shear zones belonging to the upslope extension of the Timpe fault system, was reactivated few hours after the intrusion in the SE flank of Mount Etna. This fault extends for about 8 km with a NNW-SSE trending, the southern tip of the fault is located in the city of Aci Catena whereas the northern tip reaching the village of Fleri.
In this work, we focus on a re-analysis of data collected during this seismic crisis and we show some results of a multidisciplinary dataset: i) analysis of historical and instrumental seismicity, ii) mapping of historical and last coseismic fracturing, iii) analysis of geodetic (GPS and InSAR) data.
We analyzed the historical seismicity of the Fiandaca Pennisi fault during the last 150 years, finding 15 earthquakes occurred in different segments of the fault, the major ones occured on 7th and 8th August 1894, 19th June and 25th October 1984. The coseismic effects related to the 26 December 2018 and August 1894 earthquakes show similarities [De Guidi et al., 2012].
The day after the seismic event, the GEOdynamic and GEOmatic Lab. group of the University of Catania, started the survey of ground deformation related to the earthquake of December 26 2018 following the methods already shown in De Guidi et al. [2017]. We realized 3 geodetic benchmarks along the shear zone, extending the UNICT_NET network [De Guidi et al., 2018].
The postseimic slip of the Fiandaca - Pennisi fault resulted in a mainly horizontal movement of more than 12 cm towards WNW and 10 cm towards ESE directions.
Interferometric data (InSAR) were further used to support previous investigations and to better define the geometric and the associated developed deformation zone. We have investigated the earthquake effects by SAR interferometry using the European Space Agency (ESA) Sentinel-1 A&B satellites acquisitions (C-band). For the differential synthetic aperture radar interferometry (D-InSAR) processing we used the open source Sentinel Application Platform (SNAP) toolbox.
Our data suggest that a dike, extending from the summit area SE-ward for about 2.5 km [Bonforte et al., 2019], intruded and the consequent widespread deformation of the eastern slope of Mt. Etna Volcano has perturbed and concentrate local stress field along the margin of major tectonic discontinuities [Griffith, 1921; Tsuchida and Nakahara, 1970; Soutas-Little, 1973; Boresi and Sidebottom, 1985] triggering coseismic and aseismic deformation of the Fiandaca Pennisi shear zone (26 December 2018, M_L = 4.9) and Pernicana Fault (9th January 2019 M_L = 4.1).

S1.10 - Poster

New data acquisition about space-speed vectors along the TSGA fault during the last 3 years (southern unstable slope of Mt. Etna)

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The eastern southern flank of Mt. Etna is characterized by a complex volcano-tectonic framework that is know from about 30 years. In this area, a series of structural alignment, oriented about WNW-ESE (TSGA System) are present that causing a slow eastward sliding of this area. This effect is caused probably by the intrusion of the magma across the surface, the recent lava covers that rest on the clayey substrate and due to gravity tend to slip the following “inflation-deflation cycle” during each eruption phenomena. Several interpretations of the unstable eastern flank indicate a simple gravity-controlled mechanism enhanced by magmatic intrusions. In order to detect active deformation at the southeastern edge of the unstable sector of Mt. Etna two geodetic subnetworks were established in 2010 and 2014 across the fault system We identified four blocks near the southern boundary of unstable eastern slope (Tremestieri-San Gregorio-Acitrezza fault zone), characterised by different strike and modules of velocity, separated by active fault segmentswhich are characterised by different kinematics. We obtained the velocity for each block during the period 2017-2018. The velocity for each block is: A=20,9 mm/a; B=23,2 mm/y, C= 14,3 mm/y; D= 33,5 mm/y, respectively for A, B, C and D blocks, indicating that the velocity value increases toward east. Moreover, we calculate the movement of the A, B and D block considering C stable: A = 20.71 mm/y ($_{C}V_{A}$); B = 22.80 mm/y ($_{C}V_{B}$); D = 33.3 mm/y ($_{C}V_{D}$) from west to east, this data confirms that the velocity increase toward east.

In conclusion, the horizontal velocity field increases from West to East. Probably it is controlled by both tectonic extension and/or the intrusion of dyke that could cause acceleration of the phenomenon moreover it is enhanced by the fractured clayey substrate.

S1.11- Poster

Repeating earthquakes at Mt. Etna volcano (Sicily, Italy): the North-Eastern sector case of study

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Mt. Etna volcano is characterized by several seismogenetic volumes characterized by different seismic rates and focal depths; generally, the magnitude value does not exceed 5.0. Its eastern flank is crossed by several fault systems; among these, the Provenzana-Pernicana fault represents the northern boundary. The earthquakes occurring along this structure mainly take place in the form of seismic swarms, even of low energy. During the period 2000-2019, about 18,000 earthquakes were recorded and located throughout the whole volcano by the Istituto Nazionale di Geofisica e Vulcanologia- Osservatorio Etneo (INGV-OE) seismic permanent network deployed in the Mt. Etna area.
In this work, the earthquakes of the north-eastern area of Mt. Etna volcano, taking place from 1 January 2000 to 4 June 2019 (overall 1885 events), were analyzed. We have used three stations (EMNR, EZPO, ECBD) for a double reason: a) their strategic location because close to the study area; b) their continuity of operation. By using the method of cross-correlation, 179 families of repeating earthquakes, representing approximately 37% of all the analyzed earthquakes, were found. The number of earthquakes making up the families ranges from 2 to 23. Many families consist of only two events (98 doublets), and only 12 families have ten or more events. The occurrence lifetime is also highly variable ranging from some minutes to almost twenty years. In particular, the 68.7% of the families have a lifetime shorter than three years, these families can be considered burst-type; the remaining 31.3 % have a lifetime longer than three years, and can be considered non burst-type. Only one family has a lifetime as long as the entire analyzed period. The COV (Coefficient Of Variation) was calculated on both inter-time and magnitude. As for the inter-time, the events belonging to most families show Poissonian recurrence behavior (values of COV approximately equal to 1), hence these events are unpredictable; others are temporally clustered (values greater than 1.0); only a few families have values less than 1.0. Regarding the magnitude, very low values of COV were computed (always less than 1.0), and this indicates that the earthquakes within each family have similar magnitude. Twenty-seven families, characterized by at least seven events, were analyzed in detail. It is worth emphasizing that these families fall into two main seismogenetic domains. The first is represented by the Maghrebian Chain, located in the north-eastern sector of the analyzed area, presents earthquakes families, whose events are clustered in short time intervals. In the second domain, characterized by the Provenzana-Pernicana fault seismicity, the families show a longer duration, sometimes equal to the duration of the earthquake catalog.

S1.12 - Poster

Seismicicy along the Trecastagni fault (Mt. Etna, Sicily) on February 2019

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Mt. Etna is one of the most active volcanoes in the world and is considered one of the most interesting natural laboratories for the understanding of eruptive processes and the ascent of magma. The eastern flank dynamics is controlled by several fault systems; among these, the Provenzana-Pernicana fault represents the northern boundary. From west to east, the Ragalna, Tremestieri Etneo and Trecastagni faults which in some places have evident morphological slopes make up the southern boundary of the eastern flank. The associated seismic sources are characterized by extremely superficial foci, which sometimes cause moderate damage to existing structures. Although it has been recognized as a southern boundary, these structural fault systems have not been affected in recent decades by significant seismicity, showing a low rate of occurrence. This characteristic, probably linked to the scarce detection of microseismicity and to the insufficient constraint of the seismic sources, could represent a limit of the current seismological knowledge in this volcano sector. The Trecastagni Fault (TF) is a discontinuity, with an approximately NNW-SSE trend, that develops in the southern flank of Mt. Etna, between the Trecastagni and San Giovanni la Punta villages. The seismicity of the TF is characterized by very shallow earthquakes with typical focal depths of 1-2 km below sea level. Also, south of TF, creep effects are visible along the San Gregorio di Catania fault. In recent years, some minor shallow earthquakes have been felt by the local residents, in particular, on 15 October 2009, at 00:52 GMT, M=2.1 and on 29 October 2010, at 01:37, M=2.2. Ten years after the last flank eruption of 2008-2009, on December 24, 2018 an intense seismic sequence preceded and accompanied the beginning of a flank eruption at Mt. Etna volcano. The most powerful event (ML=4.8; MW=4.9) was recorded on December 26 at 02:19 UTC and occurred just below sea level between the villages of Fleri and Pennisi. After this earthquake, the seismicity affected the central areas of the volcano and subsequently it involved more peripheral sectors including the southern structures and among these, the Trecastagni fault systems.

The purpose of this research is to study the seismicity occurred along the TF on February 2019 in the post-eruption December 2018 and their possible links with ground deformation data recorded by two extensometric stations operating in this volcano sector. In particular, we focused on three earthquakes that occurred on 6th (23:38 UTC Ml=2.5), 9th (06:02 UTC, Ml=2.9), and 10th (04:00 UTC, Ml=2.4) February 2019 which were felt by the populations living near of the epicenter area. We integrated the seismic data (P and S-phases) recorded by INGV-OE permanent seismic network with those acquired by SGR station, managed by the University of Catania and located near the fault under investigation. The integration of data has allowed improving the main hypocentral location parameters and to better associate these earthquakes with the seismogenic activity of the TF. In the same days, exstensometer data highlighted millimetric variations at both the two stations. In particular, the exstensometers showed a fault dynamic through seismic releases between February 6th and 10th and subsequently, in the period between 10th and 17th February, without seismic activity.

We believe that a multidisciplinary approach will allow to better understand the complex geodynamics of the lower southern slope of the volcano and to link it with the eruptive activity of Mt. Etna volcano.

S1.13 - Poster

Tectonic and volcanic structures in eastern Sicily as imaged by tomographic results of the TOMO-ETNA seismic active experiment

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In the central Mediterranean region, collision, subduction and different types of volcanism in a very short distance (i.e., that of Etna and of the Aeolian volcanoes) characterise the complicated geodynamic framework of the eastern Sicily and southern Calabria. The geological processes that take place here have a great influence on the tectonic evolution of the region; accordingly, their understanding are major topics in the geological research. Despite the large number of studies, the major tectonic structures of the area and their complex interaction with the magmatism are still elements inadequately constrained and matter of discussion. In this work, we present high resolution tomographic images obtained using both seismic passive data acquired during the TOMO-ETNA experiment and a selected dataset of about 5,900 earthquakes recorded by the local INGV network. Our tomography, performed with a dense grid of measure nodes, allows us to investigate in careful detail the crustal structure of Mt. Etna, the Peloritani, the southern Calabria region and of the Aeolian Archipelago. In particular, results depict major discontinuities which characterise the Aeolian area, as part of the Southern Tyrrhenian Fault System, and which extend up to the Ionian Sea. In addition, some high velocity anomalies have been found in the southern sector of Mt. Etna. Results indicate that these last features could be related to a fissural activity of an ancient volcanic edifice which was located offshore the existing volcano and which has been disrupted and modified by erosive and tectonic processes during the time, since its formation more than 220 ka ago.

S1.14 - Poster

S2. VOLCANOLOGICAL FIELD STUDIES AND TEPHROSTRATIGRAPHY

Conveners:
Stefano Branca (INGV-OE), Roberto Isaia (INGV-OV), Federico Lucchi (UniBo), Paola Donato (UniCal), Roberto Sulpizio (UniBa), Paola Del Carlo (INGV-PI)

Clustered high volcanicity in the Central sector of the Main Ethiopian Rift

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The volcano-tectonic evolution of the Main Ethiopian Rift (MER) is punctuated with periods of intense silicic volcanism, characterized by large explosive caldera-forming eruptions and the production of several ignimbrite deposits. These volcanic paroxysms require large volume of evolved silicic magma accumulated in shallow chambers into the continental crust; however, the relations between magmatism and tectonics during rifting, and the influence of the distribution and timing of regional tectonics on the ascent of magma and its stalling in large magmatic reservoirs still remain poorly defined.
We present a new, large geochronological $^{40}Ar/^{39}Ar$ dataset providing new constraints on the timing, evolution and characteristics of volcanism in the Central sector of the MER. Our survey and analyses suggest that, at least along the eastern margin of the rift, activity was clustered in periods of large magma production and emission, resulting in the recurrence of intense volcanic phases interspersed with periods of rest of volcanism. Ignimbrites and other volcanic deposits occur in the investigated area, spanning an age interval from 3.5 Ma to as recent as 150 ka. The sector is characterised by the presence of large, variably welded ignimbrite deposits and remnants of several calderas, which testify the recurrence of silicic flare-ups. We investigate in detail the eastern margin of the rift, where a large volume (hundreds of cubic km), widespread crystal-rich ignimbrite (Munesa Crystal Tuff, MCT; 3.5 Ma) is described. This ignimbrite presents at least two main units: a lower, more than 150 meters thick, densely welded deposit with columnar jointings, that can be tentatively correlated to a thick ignimbrite occurring at the bottom of geothermal wells in the central part of the rift, and an upper, pumice-bearing, unwelded unit. The MCT emission was followed, after a long quiescence, by an important phase with the emplacement of both mafic (lava flows and scoria cone) and evolved ignimbritic products between 1.9-1.6 Ma. Two widespread ignimbrite units are in fact present along the same margin, cropping out for several tens of kilometres, so testifying the high volcanicity of this sector of the MER. After this phase, volcanism occurred more frequently, possibly with a lower amount of erupted magma and still alternating with quiescent periods, clustering at ~ 1.3-1.2 Ma, ~ 0.8-0.7 Ma and ~ 0.3-0.2 Ma. These episodes of high volcanic activity will be compared with the episodic rifting of this sector of the Main Ethiopian Rift.

S2.1 - Presentazione orale

The contribution of tephrostratigraphy to assess Pleistocene paleoenvironmental changes in East Africa: the multiproxy pedostratigraphic archive of the Homo-bearing Aalat section, Dandiero basin, Eritrea

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The climatic changes during the Early-Middle Pleistocene transition are a key to understand the ecosystem dynamics that involved the Homo erectus-ergaster distribution. The Aalat pedostratigraphic succession represents a continental archive in the African Rift Valley (Eritrea), where remains of Homo at about 1 Ma were identified. The stratigraphy consists of fluvial, deltaic and lacustrine formations, which indicate a persistence of water-driven depositional environments, possibly controlled by tectonics, despite the present-day arid, desert climate [Ghinassi et al., 2009, 2015]. Paleoclimatic changes are clearly recorded by an alternation of calcic, petrocalcic (calcrete) and petrogypsic (gypcrete) horizons with Fe-oxide-stained, reddish to yellowish paleosol horizons [Scarciglia et al., 2018]. Based on high-resolution magnetostratigraphy data, the whole succession can be dated between the lower limit of the Jaramillo subchron (1.072 Ma) with normal polarity (C1r.1n) and the lower part of the normal Brunhes chron (C1n) which begins at 0.781 Ma. The Homo-bearing strata occur at the boundary between the termination of the Jaramillo event (0.988 Ma) and the upper part of the Matuyama chron with reversal geomagnetic field (C1r.1r) and ending at 0.781 Ma [Ghinassi et al., 2015]. Detailed sedimentological, paleontological, paleoanthropological, pedological and stable-isotope investigations contributed to interpret the alternation of cemented calcrete/gypcrete layers and red paleosols as driven by cyclical changes from dry to wet environmental conditions, which fit well with aeolian dust fluxes and marine isotope stages of glacials and interglacials at higher latitudes [Scarciglia et al., 2018]. Despite the robust geochronological frame, the age of the upper boundary of the Aalat pedosedimentary archive was not well-constrained: it could be simply considered younger than 0.781 Ma. In order to obtain such missing information on the late-stage emplacement of the geological record and a consequent detailed paleoclimatic reconstruction, we analyzed three tephra layers located at the bottom (TP1, TP2) and especially at the top (TP3) of the Aalat succession. Indeed, previous dating of intercalated tephras failed more than once because of the unavailability of suited, well-preserved, unweathered materials. Therefore, we tried to assess the composition, potential provenance and chronology of the three volcanic layers, based on morphological observations and compositional analyses performed on glass fragments and pyroxenes using scanning electron microscopy coupled with energy dispersive spectroscopy (SEM-EDS). Our results revealed the presence of vesicular pumices and/or shards with rhyolitic composition in all the samples and few loose clinopyroxenes (augite) in the basal tephras only. However, the two basal tephras cannot be correlated to any proximal or distal known deposit. On the contrary, more than one correlation is possible for the uppermost layer, chemically similar to other Pleistocene tephras dispersed in Eastern Africa, ranging in age between 0.751 and 0.709 Ma. Despite this upper tephra cannot be interpreted univocally as ejected during a unique eruption and its age of emplacement remains uncertain, the good correlation of the pedogenic horizons with major Pleistocene paleoclimatic shifts and corresponding global-scale curve, allowed us to exclude the Silbo tuff (0.751 Ma) as a potential candidate, given the stratigraphic position of the upper calcrete horizon almost immediately below it and its correlation to MIS 18 (peaked at ca. 720 ka). Therefore, TP3 could correspond to one of the younger tephras from the Melka Kunture close to this time interval, such as MK27-20 (0.726 Ma) or MK27-09 (0.709 Ma). This new time constraint to the top of the Aalat section permitted us also to estimate long-term sedimentation rates for three time slices across the whole record: 0.83 mm/a during the Jaramillo event, 0.77 mm/a during the final part of the Matuyama epoch, and in the range of 1.34-0.76 mm/a in the final part of the succession.

S2.2 - Presentazione orale

The 430-365 ka tephra record from Fucino Basin, central Italy: implications for the Mediterranean tephrochronology and the peri-Tyrrhenian explosive volcanism

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Past explosive volcanism is commonly reconstructed using near-vent deposits, where the geological record provides fundamental information useful for evaluating eruptive and emplacement dynamics, and the evolution of the volcanic edifice. Due to the occurrence of coarse-grained crystals, proximal outcrops are also suitable for direct isotopic dating techniques, such as $^{40}Ar/^{39}Ar$. However, intense volcano-tectonic and sedimentary processes occurring close to a volcano cause proximal outcrops to be often fragmentary and incomplete [Giaccio et al., 2014] and the eruptive history to be only partially represented and/or directly observable. In contrast, distal archives can continuously record sedimentation of ash (tephra) layers, providing useful integrative information for a better reconstruction of the history and dynamics of explosive volcanic activity [Albert et al., 2019]. During the Quaternary, large lake systems hosted in intermountain basins in central-southern Apennines (e.g. Fucino and Sulmona), recorded tephra deposition from the peri-Tyrrhenian and insular volcanic districts, including Vulsini, Vico, Sabatini, Colli Albani, Somma-Vesuvius, Phlegrean Volcanic District, Ischia, the Aeolian Islands and Mount Etna, which were characterised by an intense and recurrent explosive activity [Peccerillo, 2017]. Recent studies highlighted the huge potential of the Fucino basin to provide a near continuous record of ash fall events in the region, including ~130 tephra layers spanning the last 430 ka [Giaccio et al., 2017; 2019].
Here we present detailed geochemical and geochronological data of 34 tephra layers preserved in the lacustrine succession of the Fucino basin spanning the time interval of ca. 430-365 ka interval, equivalent to the Marine Isotope Stage 11. The 34 tephra layers can be ideally divided into three compositional groups (CG): CG-1 includes a series of K-foidites and as such are easily associated to the Colli Albani activity; CG-2 includes tephra layers with tephritic to phonolitic compositions; and CG-3 includes a series of trachytic and/or rhyolitic tephra. Since most of the available geochemical and geochronological data for the potential proximal counterpart are scant and/or not suitable for tephrochronological purposes (e.g., whole rock chemical composition), we also determined the glass compositions and the $^{40}Ar/^{39}Ar$ ages of some prominent eruptive

units from Vico volcano covering the ca. 430-390 ka time interval (Vico Period I) [Perini et al., 1997]. The combination of data collected from both the proximal and distal sedimentary settings allowed us to correlate several tephra layers to their volcanic source and, in some cases, to specific eruptive units, thus transferring high-precision $^{40}Ar/^{39}Ar$ ages determined on the relevant proximal eruptive units into the Lake Fucino succession. This allowed us to develop a robust age-depth model for the 430-365 ka time interval that provided a fundamental geochronological framework for both the paleoclimatic record and the timing of major and minor explosive events at the various peri-Tyrrhenian volcanic districts, which in turn is fundamental for volcanic hazard assessment purposes.
Our data add information fundamental to the Mediterranean tephrochronological framework, which is crucial for both addressing paleoclimatic issues, and for a better understanding of the history of the peri-Tyrrhenian explosive volcanism. From a wider methodological perspective, our results highlight how a multidisciplinary approach, which integrates data from both distal and near-source volcano-sedimentary records, is pivotal to establish a robust regional and extra-regional reference tephrochronological framework. This has clear applications within the wider context of the Quaternary sciences and volcanology and a systematic future application of this approach to other volcanoes is needed.

S2.3 - Presentazione orale

The Late Pleistocene to Holocene tephrochronological record of ND_14/Q core in the Southern Adriatic Sea

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A tephrochronological investigation was carried out on the composite marine core ND_14/Q collected in the frame of The NextData Project on board of Urania RV/CNR (July 2014). The core was raised in the Southern Adriatic Sea, offshore the Gargano promontory, at a water depth of 1013 m b.s.l. and penetrated totally a 5.35 m long succession composed by hemipelagic sediment with intercalated one visible tephra and thirteen cryptotephra deposits. These latters have been recognized through magnetic susceptibility means and observation at the optical microscope of samples prepared for micropaleontological purposes. Stratigraphic intervals characterized by high values of magnetic susceptibility (up to 12 cm) were sampled at 1 cm-step and selected materials were picked up for chemical analyses. In total, twenty-one samples representative of the studied layers have been characterized in terms of major element composition through SEM-EDS technique. The analysed materials display K-alkaline and sub-alkaline features and their chemistry points to a correlation with the Somma-Vesuvius, Campi Flegrei and Lipari Island (Aeolian Arc) volcanic activity occurred during the Late Pleistocene-Holocene. In detail, major marker tephra of the Central Mediterranean linked to plinian and sub-plinian events have been recognized, among which the phlegraean Neapolitan Yellow Tuff (ca. 15 ka), Pomici Principali (ca. 12 ka B.P.) and Astroni-Agnano Monte Spina (ca. 4.2 ka-4.4 ka B.P.) eruptions and, for the first time in this area, the vesuvian 1631 event. The very well preserved Mercato (ca. 9 ka B.P.) and Fiumebianco-Gabellotto (ca. 8.4 ka B.P.) cryptotephra have also been found thus providing an excellent chronological framework for the Sapropel S1 definition in the succession which definitely records the last ca. 22 kys (Pomici di Base tephra). A number of cryptotephra with uncertain source event, already documented in the studied area by Siani et al. [2004] and by Matthews et al. [2015] have also been found such as a Somma-Vesuvius related tephra comparable in composition to the Mercato (ca. 9 ka B.P.) deposits. It was found immediately above the Agnano Pomici Principali tephra, enabling us to hypothesize the occurrence of explosive activity at the volcano between Greenish (ca 19 ka B.P.) and Mercato eruptions. The products of this activity, generally referred to by the acronym "GM", have not well defined proximal equivalents; this consideration points out that new investigations are necessary to characterize and define proximal counterparts of these eruptions. The results obtained in this work, integrated with a number of radiocarbon datings along the record, allowed us to obtain an accurate chronological framework for the ND_14/Q continuous succession thus providing an excellent marine archive for palaeoclimate research.

S2.4 - Presentazione orale

Correlation between submerged and continental infill at Campi Flegrei caldera: insights on the volcano-tectonic events of the last 15 kyr

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The Campi Flegrei caldera (southern Italy) is characterized by over one-third of its extension lying below the sea. In the last 15 kyr the caldera floor has suffered hundreds of meters of ground deformation alternating uplift and subsidence episodes in response to the activity of the volcanic system. The evidence of significant uplifts is witnessed by the occurrence of marine sequences exposed on land, both along a 30 m high La Starza cliff and in numerous well logs. However, most of these sediments are currently hidden below the sea. This work aims to reconstruct the marine counterpart of the infill by using large multiscale reflection seismic data (> 100 profiles) and an accurate seismic facies analysis. The latter consisted in the study and comparison of seismic attributes, scaled to the resolution of the different datasets, to their geological analogs on land. Furthermore, by observing the changes in pattern of on-lap terminations, thickness, amplitude, and distribution of erosive features of different horizons, we tentatively ascribed these sequences to the well-known continental deposits. The study of the whole sequence above the Neapolitan Yellow Tuff (15 ka) allowed us to gather relevant information about the relationships between stratigraphic record, ground deformation and sea level changes. In particular, the reconstruction of buried surfaces gave us hints on the evolution of the volcanic system including the role of faults in terms of estimation of displacement and relationships with the different epoch of major eruptive activity.

S2.5 - Presentazione orale

Discharge of volcanic products and climate-controlled variation of the sedimentary supply in the volcanostratigraphic succession of Mt. Etna

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This study focuses on the epiclastic deposits which are exposed along the main fault scarps of the eastern flank of Mt. Etna and have been drilled in the region of Santa Venerina. The detailed field mapping, combined with the available radiometric age of lavas and the results of petrochemical analyses of the main drilled lithostratigraphic horizons indicates that the epiclastic deposits form three main key-levels, which interrupt the volcanic series. The oldest clastic horizon, here named Acireale Formation, covers a marked erosional surface entrenched in alkaline lavas showing radiometric age from 140 ka to 132 ka [Gillot et al., 1994; Branca et al., 2008; De Beni et al., 2005; 2011]. It consists of a reddish fine tuff, containing little channel filled by centimetric sized clastic conglomerates and breccias with lava blocks immersed in fine grained deposits. On top of the Timpa of Acireale, the Acireale Formation underlies coastal marine deposits that are covered by alkaline lavas, as old as 120 ka [De Beni et al., 2005; 2011]. The marine terrace can be thus attributed to the OIS 5.5 (125 ka). Consequently, the age of the Acireale Formation is constrained between 132 ka and 125 ka, and its deposition refers to the eustatic sea level rise immediately before to OIS 5.5. The intermediate epiclastic unit, here named Santa Venerina Formation, are made of lower breccias, showing volcanic blocks immersed in a sandy matrix, capped by upper conglomerates, with well-rounded volcanic pebbles. Considering the age of the volcanic horizons at the top and at the bottom [Gillot et al., 1994; Branca et al., 2008; De Beni et al., 2011], the Santa Venerina Formation can be confined between 60 and 15 ka. The youngest clastic deposits form a wide alluvial fan, well-known in literature as “Chiancone” [Rittmann, 1973]. This clastic wedge can be divided into two sequences [Romano, 1982; Calvari and Groppelli, 1996]. A radiometric age of 15 ka [Calvari and Groppelli, 1996] refers to the lower sequence, which constitutes the backbone of the alluvial fan. The upper sequence, showing radiometric age of about 7 ka [Calvari and Groppelli, 1996], consists of conglomerates that infill paleo-channels entrenched within the lower sequence and drapes the earlier products of the Recent Mongibello. These volcanoclastic deposits are distributed as far as Santa Venerina, where reddish clay horizons, containing pebbles from crystalline basement-rocks, are dominant. Petrochemical analyses carried out on samples took in a borehole located in the village shows an upward progressively ageing of the provenience rocks from the Mongibello lava products, to the ancient alkaline lavas and sedimentary rock.

Our data evidence that in the eastern flank of Mt. Etna, the discharge of high volumes of lava flows and pyroclastic deposits drove the rapid accumulation of the relief was cyclically exceeded by periods of intense erosion and clastic production, likely corresponding to the main deglaciation processes. The climate-controlled variation of the sedimentary supply combined with eustatism, out of the Etnean area, produced few meter-thick highly discontinuous sequences composed of distinct unconformity bounded wedges that cumulated at the base of slope. Along the coast, the Late Quaternary clastic wedges form distinct marine terraces due to the generalized tectonic uplift of the region. On the contrary, at Mt. Etna the rate of supply was largely higher, due to the impressive relief cumulated by emissions of huge volumes of volcanic products that provided the production of large amounts of clastic material.

S2.6 - Presentazione orale

Volcanological and chronological characterization of the recent (last 2000 years) rhyolitic eruptions of Lipari (Aeolian Islands, Southern Italy)

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Lipari is the largest island of Aeolian Archipelago (Southern Italy). The youngest eruptive products (tephra and lavas) were all emitted in the north-eastern sector in the last 2000 years. Whilst these eruptions represent some of the youngest activities in the archipelago, the timing and chrono-stratigraphic relationship between the eruptive deposits of Mt. Pilato, Forgia Vecchia, Lami, and Rocche Rosse have remained controversial.
Here, the products of the four centers have been studied through a combined stratigraphic, microanalytical, paleomagnetic, and radiometric approach in order to clarify their absolute and relative chronologies to one another, and to characterize the emplaced tephra. Forty-three samples, distributed on 16 outcrops representing the different stratigraphic sequences, were studied in laboratory through sedimentological (grain-size and componentry) and geochemical (major and trace elements) analyses. Paleomagnetic dating of four representatives effusive (Forgia Vecchia and Rocche Rosse lava flows) and two explosive, densely welded deposits (Rocche Rosse and Lami) were carried out. This data set was integrated with two new radiocarbon (^{14}C) determinations on charred material from underlying the Forgia Vecchia tephra deposit.
Major element chemistry and textural analyses of the juvenile component indicate that Forgia Vecchia tephra has more evolved compositions (SiO_2=75.35 wt.%; Na_20+K20=9.05 wt.%) than the other eruptions, the tephra consists of highly vesicular juvenile fragments and lithics belonging to the disruption of intermediate composition lavas. Monte Pilato tephra products (SiO_2=74.75 wt.%; Na_20+K_20=9 wt.%) show, from base to top, a sharp decrease in the vesicularity of juvenile fragments coupled with an increase in obsidians content and an increase of bedding of the deposit. Accidental lithics consist of fresh to moderately altered mafic to intermediate lavas. Rocche Rosse tephra products (SiO_2=74.55 wt.%; Na_20+K_20=9.05 wt.%) are characterized by poorly vesicular juvenile and obsidians clasts, which become more abundant towards the top of the sequence. Lithics are represented by rhyolitic lava clasts with varying degrees of alteration. Tephra resulting from the local activity of Lami (SiO_2=75.3 wt.%; Na_20+K_20=9.08 wt.%) is represented by highly vesicular, fibrous juvenile clasts of gray color, with prevailing prolate shape, breadcrust bombs and block and grey obsidians. Accidental lithics consist of lavas of rhyolitic composition.
Paleomagnetic data and 14C datings indicate that around AD 1300 the north-eastern sector of Lipari was affected by continuous volcanic activity from different vents. The eruption of Mt.

Pilato occurred during the VIII century, as already suggested by a previous ^{14}C dating and was thus followed by a period of eruptive stasis identified by a series of visible erosional discontinuities. The activity resumed during the second half of XIII century with the Forgia Vecchia eruption that included both an explosive and an effusive phase. This was rapidly followed by the Rocche Rosse and Lami eruptions, which went on pene-contemporaneously.
While Rocche Rosse occurred in the same area of Mt. Pilato, Lami consists of a local vent on the southern sector of Mt. Pilato cone. Rocche Rosse, Lami and Forgia Vecchia are thus aligned along a N-S fracture line indicating that their initiation was promoted by the activation of the same structural element. The simultaneous activation of volcanic vents on Lipari and on the island of Vulcano (Breccia di Commenda eruption) about 8 km to the south, along the same N-S fissure in turn indicates that the tectonic line had a significant role in the regional character of eruptive activity.

S2.7 - Presentazione orale

Paleomagnetic dating and correlation of Etna volcano (Sicily) prehistoric lava flows in the urban district of Catania

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The city of Catania, in its millenary history, was directly damaged by the devastating impact of the lava flow produced during the 1669 AD eruption [Branca et al., 2016]. However other lava flows reached the Catania area in prehistoric ages, before the birth of the city itself. In this work, the lava flows of Barriera del Bosco and Larmisi, bracketed between 15 and 3.9 ka BP, and that of San Giovanni Galermo, emitted between 3.9 ka BP and 122 BC [Branca et al., 2011], were paleomagnetically studied in order to better date and correlate them. In each lava flow, four different sites were sampled (12 sites in total), and in each site ten oriented cores were gathered (120 cores in total), which were demagnetized by alternating field cleaning at the INGV paleomagnetic laboratory of Roma. The analysis of paleomagnetic directions represents one of the most powerful and precise dating tools for volcanic products emitted in the last thousands of years [Speranza et al., 2008]. Moreover, petrographic analyses have been carried out on some samples collected from several sampling sites with the aim of helping to further distinguish the three lava flows among them and better correlating them to the different sites. We restrict the paleomagnetic ages of the studied flows to 9300 BC - 4400 BC (Barriera del Bosco), 3800 BC - 2300 BC (Larmisi) and 3500 BC - 2000 BC (San Giovanni Galermo).
Dating past eruptions and accurate knowledge of an active volcano like Etna, in terms of spatial distribution and temporal frequencies, is of fundamental importance for hazard assessment, especially for densely inhabited areas as Catania and the other cities located in the lower south-eastern slope of the volcano.

S2.8 - Presentazione orale

A case study from Mount Etna for the emplacement of a clastogenic lava flow

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A lava-fountaining episode occurred on Mount Etna on the 18th May 2016. As a consequence, the summit craters were filled by pyroclasts, till the formation of a clastogenic lava flow, which spilled out from the Bocca Nuova crater and flew on the western flank of the volcano.
The aim of this work is to understand the rheological behaviour of both the ejected products and the flow. It was performed a suit of high temperature (1050-1100 °C), uniaxial deformation experiments at a constant strain rate (strain rate 10^{-4} s^{-1}) on natural crystal-vesicle bearing samples coming from the May 2016 episode. Samples were collected on the summit area (pyroclasts) and along the flow, making a distinction as a function of the vertical profile with the distance from the emission point.
The rheological behaviour changes progressively in agreement with the variation of the textural features: vesicles show minimum values along the flow (10-25%) and maximum values in pyroclasts (56%), while crystal content seems not to influence the rheology significantly.
A suite of experiments was performed at 3 different experimental temperatures and constant strain rate of 10^-4 s^{-1}, showing deformation both within the brittle and the ductile regime, depending on the increase in vesicle content and temperature: results show that samples having a high vesicle content tend to maintain their brittle behaviour, whereas in denser samples, together with the temperature increase, the ductile deformation dominates.
By combining textural and rheological data, field observations of the 2016 clastogenic lava flow are confirmed. due to sintering and compaction were responsible of a marked decrease in vesicle content from the pyroclasts to the overflowing zone, promoting lava viscous flow, as experiments confirmed. Subsequently, autobreccia formation due to the brittle behaviour were favoured by the down flow porosity increase.

S2.9 - Presentazione orale

Valuation of flow and emplacement temperatures reached by PDCs using charred wood analysis

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Pyroclastic density currents (PDCs) are among the most hazardous of all volcanic processes in terms of potential damages within their areal extent due to their concentration and velocity (dynamic pressure) and temperature. Despite our knowledge on stratigraphical and sedimentological characteristics of PDCs deposits and the attempts of modelling their flow behaviour, our understanding of these complex volcanic processes is still far from complete. Physical properties variation such as velocity, density and temperature and how they interact among each other and with the topography during flow is still matter of debate and study.
Temperature evaluation of PDCs has been recently performed using optical analysis of charred wood (Reflectance analysis - Ro%) embedded within the pyroclastic deposits.
The validity of this proxy for the emplacement temperature assessment, has been established in different case studies (Fogo Volcano, Merapi Volcano, Colima Volcano, Doña Juana Volcano, Ercolano-Vesuvius Volcano), resulting comparable with the already well know paleomagnetic analysis (pTRM).
Due to its not retrograde nature, the process of carbonification records over time the maximum temperatures experienced by the wood fragment/tree trunk/furniture.
This peculiarity has great importance in terms of timing of charring events, as the charred wood can record the possible temperature fluctuations in case of multiple pulses event.
This allows us to reconstruct the thermal and dynamic of PDCs history at different steps.
Reflectance analysis (Ro%) results display samples with homogeneous charring temperature (same Ro% values) from rim to core and others with different charring temperatures throughout the sample. Ro% of the latter usually infer higher temperature on the edge of the fragment/tree trunk than in the inner part. This bimodal behaviour can be attributable to multiple temperatures exposure, occurred during diachronous events of flow and deposition.
The higher temperature of the rim compared to the core, can be related to the very first moment of the PDCs passage, when the wood fragment/tree trunk/furniture was still in situ; while the internal carbonification at lower temperature can be attributable to a subsequent heating process occurred during and after the PDCs emplacement.
Therefore, within the same fragment/tree trunk we can extrapolate PDCs temperature information related not only to equilibrium (emplacement) condition but, more importantly, to dynamic (flow) regime. The application of such valuable and accurate method allows the estimation of the total heat dispersion during the transition from flow to deposition conditions.
This study opens a promising new frontier to evaluate the maximum PDCs temperature based on the degree of charcoaling of wood fragment/tree trunk/furniture affected during the event.
Temperature estimation of dynamic PDCs temperature bears important implication in terms of hazard assessment.

S2.10 - Presentazione orale

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

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Despite the large number of studies, the transport and deposition of pyroclastic density currents (PDCs) have remained a most debated issue in volcanology. Some explosive eruptions withdraw magma volumes of several hundred cubic kilometers, generate very large PDCs and the deposits can extend more than 100 km from their vent. Fundamental questions concern about the long run-out distances and what the propagation flow mechanism and the physics are behind these very large PDCs. One of these large-volume PDCs is the Campanian Ignimbrite (CI), the case study of this work, related to a caldera-forming eruption that occurred 39.8 ka in Campi Flegrei. The CI is widespread over an area of 7,000 km^2, with a final runout of about 80 km and deposits can be found at an elevation of around 1,000 m above sea level. In spite of the large number of studies, some questions are still open. The Dense Rock Equivalent (DRE) volume estimates range from 60 to 300 km^3. This work presents a new estimate of the volume constrained by an isopach map that reconstructs the paleo-topography during the eruption. The total final volume estimate of the eruption ranges from 415.0 km^3 to 527.8 km^3 (164.9 km^3 - 210.7 km^3 DRE). This value corresponds to a mass of 4.30 - 5.49 x 10^14 kg, a magnitude of 7.7 and a VEI of 7. The thickness data were used to analyze the PDC interaction with the paleo-topography, using the topological aspect ratio (ARt). A great effect of blocking is evident in front of topographic barriers, while a strong channeling occurred in the paleovalleys. Three different systems were recognized: a transport system, a sedimentation system and a depositional system. The transport system was extremely diluted and an index of a high energy flow, which developed the sedimentation system as the flow reached the topographic barrier. Depositional features, including valley-pond deposits with flat tops, the lack of veneer facies and of deposit at steep slopes suggest a near Newtonian behavior of the fluidized granular undercurrents of fine ash particles downhill generated by the sedimentation system. The undercurrents have clear signs of a subcritical flow, thick and relatively slow. Both the indexes of high and low energy current (as sub and super-critical flow) suggests that CI can be considered as a new end member of ignimbrites.

S2.11 - Presentazione orale

Stratigraphy and geochemistry of the Brown Tuffs from the Aeolian Islands (Italy) indicates Vulcano was frequently active over 70 ka and produced widespread ash dispersals

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The Brown Tuffs (BT) are widespread reddish-brown to grey, ash-rich pyroclastic deposits recognized in the post-80 ka stratigraphic sequences on most of the Aeolian Islands and the Capo Milazzo peninsula (Sicily). They have very homogeneous lithological, textural and sedimentological features which make it difficult to establish robust correlations of units between the islands and to the proximal vent(s).

Here we present a large dataset of textural features, and major and minor element glass geochemistry of juvenile glass components for most BT depositional units from exposed stratigraphic profiles on the main islands of Vulcano and Lipari, which are fully representative of the complete BT succession. The distinctive chemical groupings observed within the glass analyses, both temporally and spatially, allow us to recognize different BT units. Geochemical analyses have allowed us to fingerprint the three main stratigraphic macro-units in which the BT had been previously subdivided on the basis of the interlayered Ischia Tephra (Monte Epomeo Green Tuff; 56 ka) and Monte Guardia pyroclastics from Lipari, the latter newly radiocarbon dated to 27-26 ka. Lower (70-56 ka; LBT), Intermediate (56-27 ka; IBT) and Upper BT (26-8 ka; UBT) yield K-series volcanic glasses ranging from basaltic trachy-andesites, through trachyandesites, to more evolved trachytes. The UBT are clearly distinguished from lower units by more evolved (exclusively trachytic) compositions. They also display lower TiO_2 contents and show a progression towards more evolved compositions over time. This has made it possible to re-define the geochemical-evolutionary boundary between IBT and UBT in the proximal areas on Vulcano. The IBT to UBT change occurs at the 24 ka Spiaggia Lunga scoriae on Vulcano, which is stratigraphically higher than the previous IBT-UBT boundary marker (Monte Guardia).

The glass compositions provide correlations to well preserved eruption units on the island of Vulcano. Thus, the BT units are potentially proximal equivalents of distal volcanic ash that is recorded in distal terrestrial and deep-sea archives, representing a powerful tool for correlating volcanic and tectonic events across whole Aeolian archipelago and southern Tyrrhenian Sea. In addition, new geochemical analysis (glass) of exotic tephra layers interlayered within the BT succession allow us to strengthen their correlation to key widespread chrono-stratigraphic markers derived from the Campanian volcanoes that are also traced between sedimentary archives across the Central Mediterranean region.

Interestingly, the homogeneous UBT compositions are fairly similar to those of the early pyroclastic products (Punte Nere) by the La Fossa cone on Vulcano, indicating the corresponding magmatic system has erupted similar melts over the last 24 ka. This significantly extends the time interval over which there has been eruptive activity within the La Fossa

Caldera, with deposits displaying similar features to those of the presently active La Fossa cone. According to this new information, the potential scale and impacts of future eruptions from within the La Fossa caldera should be reconsidered.

S2.12 - Presentazione orale

New insights on the structural setting of the Pisciarelli fumarole field (Campi Flegrei caldera): implications for evolution and eruptive scenarios

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The Solfatara-Pisciarelli area, with its fumarole fields, currently is the most active sector of the Campi Flegrei caldera, hosting an intense hydrothermal activity, whose shallower expression is ruled by a complex pattern of fractures and faults. Recently, geochemical and seismic monitoring network of INGV-OV is recording important changes in the area, making a detailed definition of the structural pattern of the area of fundamental importance. Volcanological and structural studies may be the key to disclose the relationships between structures, as fault and fractures, and fumarolic and hydrothermal activity. Furthermore, this study could provide basic information to understand the dynamic processes and possible eruption scenarios for this sector of the Campi Flegrei caldera. For this purpose, we present a volcanological and structural survey, whose results have been compared and interpreted with geophysical data. The survey led us to improve the geological map of the Solfatara-Pisciarelli area, as well as the fault and fracture datasets. The rocks, exposed in the Pisciarelli area, host a large number of faults and fractures, often related to fault damage zones. Meso-scale faults and fractures were characterized by means of stereographic projections, contour maps, and rose diagrams. This characterization reveals the occurrence of four fault and fracture sets characterized by E-W, N-S, NW-SE and NE-SW directions. All the observed faults show normal separations. Extension directions were calculated for conjugate fault sets in different sites of the area, and an S3-vector (fractures) and T-axis (faults) direction map were reconstructed. Cross-cutting fault and fracture relationships and their relations with the volcanic sequences reveal that NW-SE and NE-SW trending faults are sealed by Solfatara deposits (4.28 ka); whereas the other two sets cross-cut the youngest volcanic succession (Astroni deposits, 4.25 ka). Three ERT profiles, two of which passing across the Pisciarelli mud pool, were carried out during the geological survey. The results have been used to better define the structures at depth, as shown in three geological cross-sections. Several landslides characterize the higher part of the Pisciarelli fumarole field, likely favoured by different factors, including (i) intense rock fracturing; (ii) hydrothermal alteration; (iii) mud-pool activity and (iv) steep relieves surrounding the mud pool. Along the slope, at about 5 meters above the present mud pool level, we recognized ancient landslide deposits overlying mud sediments, similar to those nowaday forming within the active mud pool. We suggest that a landslide could plug the mud pool, acting as trigger mechanism for hydrothermal explosions at Pisciarelli, as described for other hydrothermal systems in the world.

S2.13 - Presentazione orale

Use of UBSU cartography on volcanic deposits: the example of Monte Amiata (Southern Tuscany, Italy)

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The geological units adopted by the Italian Geological Survey in the volcanic stratigraphy and cartography are the Unconformity Boundary Stratigraphic Units (UBSU), which are defined as a rocky body bounded on the top and bottom by specific, significant, and demonstrable surfaces of geologic discontinuity. The basic unit is the Synthem, which can be divided into two or more Subsynthems. This cartographic criterium has been applied to the survey of the Monte Amiata volcano. More than 30 litho-stratigraphic units has been mapped, and inside these units, eleven Formations have been described and formally defined. The use of UBSU criteria made possible to group all these units in only two Synthemes and five Subsynthemes. The limit between the two recognized Synthems corresponds to a significative geologic discontinuity associated with a saprolitic soil developed by in situ physical disaggregation of the underlying acidic lavas that constitute the parent rocks. The application of the UBSU stratigraphic units allowed to propose a geological evolution of the Monte Amiata volcano comprising two main period of activity that correspond to the older Bagnore Synthem and the younger Monte Amiata Synthem. They are separated by a major unconformity corresponding to a surface of erosion, saprolithic weathering and tectonic deformation. Into the Bagnore Synthem, there are two Subsynthem. The lower, the Bagnolo Subsynthem comprises several great lava flows characterized by a vitrophyric perlitic groundmass. They flowed for very long distances (up to 8 km) in all the directions (e.g. Sorgente del Fiora Fm., Marroneto Fm., Piancastagnaio fm., Abbadia San Salvatore fm., Vivo d'Orcia fm.). A surface of erosion and unconformity separates the Bagnolo Subsynthem from the overlying Montearioso Subsynthem. It is composed of more confined vitrophyric lava flows (e.g. Tre Case Fm., Quaranta Fm., Castel del Piano fm.) and one exogenous lava dome and coulee (Poggio Pinzi fm.). All the rocks belonging to the Bagnore Synthem show a well-developed weathering that transformed their uppermost portion in a sandy deposit, yellow and reddish in color. The Monte Amiata Synthem comprises three Subsynthems. The lower Valle Gelata Subsynthem is characterized by exogenous lava domes with thick coulees (e.g. Poggio Lombardo Fm., Pozzaroni Fm.) and by long channelized lava flows (e.g. Leccio fm., Coderino fm.). The intermediate Madonna degli Scout Subsynthem is composed of several exogenous lava domes with short coulees (e.g. Poggio della Pescina Fm., Poggio Falco Fm., Corno di Bellaria Fm., La Vetta fm., Rifugio Cantore fm.), and minor lava flows. All these units are emplaced upon a morphology that has been moulded by tectonic deformations. The final Prato della Contessa Subsynthem comprises several exogenous lava domes (e.g. La Montagnola fm., Pianello fm.) and lava flows (e.g. Ermeta fm., Le Macinaie fm., Cancelle fm, Fosso La Cocca fm.) from the volcano summit area, and the lateral exogenous lava dome and coulee of the Trauzzolo Fm.

S2.14 - Presentazione orale

A distal tephra record of the early Lower Pleistocene explosive activity of the Campanian Plain volcanism from L'Aquila lacustrine succession, central Italy

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A 230 m-long sedimentary core (CN1) was bored from the Paganica-San-Demetrio Castelnuovo (PSC) Basin, in L'Aquila area, Central Italy. The drilled sedimentary succession consists in massive to laminated whitish to greyish lacustrine marls and clays belonging to the San Nicandro Formation. The latter is a deep lake facies belonging to the oldest synthem of PSC Basin including different slope, alluvial, fluvial, deltaic and lacustrine deposits, hosted in the NW-SE trending extensional continental PSC Basin [Nocentini et al., 2018].
Several centimetric thick tephra layers occur in the interval between 30 m and 105 m depth of the sedimentary core CN1 and in two outcropping sections of the deep-lake deposits of the San Nicandro Formation. All tephras from core CN1 and outcropping sections share a common lithology of greyish ash made up of moderately vesicular glass shards, clinopyroxene, plagioclase, and minor orthopyroxene. A preliminary $^{40}Ar/^{39}Ar$ dating of plagioclase crystals extracted from the uppermost and thicker layer SNC2, occurring in both outcropping succession and at 30 m-depth in core CN1, yielded the age of 1.74±0.4 Ma. Glasses and whole rock sampled have a calc-alkaline affinity with an intermediate composition ranging from basaltic-andesite to andesite. Initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values of whole rock samples range from 0.706574±0.000005 to 0.706661±0.000006 and from 0.512372±0.000006 to 0.512379±0.000005, respectively, while initial $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values range, respectively, between 19.207±0.001 and 19.263±0.008, 15.681±0.001 and 15.724±0.006, 39.242±0.002 and 39.365±0.015. Incompatible trace elements normalised to the primordial mantle display typical subduction-related patterns with troughs at Ta, Nb, and Ti, and peaks at Pb. These geochemical evidences and the petrographic features of SNC samples (the two-pyroxene paragenesis with abundant An-rich plagioclase) are strongly suggestive of a provenance from the Plio-Quaternary calc-alkaline activity that occurred in the Voras region (Balkan peninsula) [Beccaluva et al., 2007] and along the Tyrrhenian margin of the Apennines from Tolfa to Campanian regions [Conticelli et al., 2015]. However, Sr-, Nd-, and Pb-isotope ratios of SNC samples significantly differ both from Voras rocks (Balkans) and calc-alkaline volcanic rocks erupted in the same period in Tolfa, Manziana and Cerite districts (Central Italy); conversely, they are within the range of the Early Pleistocene Campanian volcanism. Specifically, both chronology and geochemical (mayor, trace and isotope) composition of the analysed tephras are compatible with the 2 Ma old volcanic rocks founded in deep boreholes in Campanian Plain, southern Italy [Albini et al., 1980]. Based on this preliminary strong consistence

of geochronological and geochemical data, the investigated tephra succession could represent the first distal evidence of the Early Pleistocene calc-alkaline volcanism of the Neapolitan-Campanian area. The ongoing investigations will allow a comprehensive geochronological and geochemical characterisation of the whole CN1 tephra succession, essential to well constrain the age model of the CN1 succession, with potential implications for both Lower Pleistocene central Mediterranean tephrochronology and the volcanological and geochemical evolution of the earliest Campanian calc-alkaline explosive volcanism.

S2.15 - Poster

Holocene caldera-forming eruption from Mt. Rittmann in the marine record of Antarctica: volcanological reconstruction and hints for its paleoenvironmental significance

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The near-source exposure of eruption deposits at Antarctic volcanoes is often limited owing to glacial processes making volcanological reconstructions challenging. Fortunately, 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.
We report here the first results from PNRA - TRACERS project (TephRochronology and mArker events for the CorrElation of natural archives in the Ross Sea, Antarctica). These tephrochronological and tephrostratigraphical results are from four sediment cores recovered from the Wood Bay area in the western Ross Sea, Antarctica. In all the analyzed sediment sequences we discovered a spectacular, stratified primary tephra named the Aviator Tephra (AVT) of considerable thickness, up to 80 cm. According to the tephra characteristics and dispersal, the eruption that emplaced it had been of considerable intensity and potentially represent one of the largest Holocene eruptions ever recorded in Antarctica. Eruption dynamics were initially dominated by hydromagmatic magma fragmentation conditions producing a prolonged, sustained, relatively wet and ash-rich eruptive cloud. The eruption then evolved into a highly energetic, relatively dry magmatic Plinian eruption. The final phase of the eruption was then characterized by renewed efficient magma-water interaction and/or collapse of the eruptive column producing pyroclastic density currents and associated co-ignimbritic plumes. Based on the major and trace element geochemistry and the mineral assemblage of the tephra, Mt. Rittmann was identified as the tephra source and a Holocene age was determined by ^{14}C and Ar/Ar methods. Deposits studied might be linked to widespread lag breccia deposits previously identified on the rim of the Mt. Rittmann caldera having the same geochemical composition.
In addition, the tephra provides important paleoenvironment information by demonstrating that the Wood Bay was characterized by open sea conditions at the time of the tephra deposition possibly much before than previously thought. AVT is also an excellent tephrostratigraphic marker for the Wood Bay area, in the Ross Sea but, considering the product nature and dispersal it reasonable that it could be crucial for future synchronization between continental ice and marine archives of this region.

S2.16- Poster

New geological mapping and revised eruptive and magmatic history of Ustica island (Southern Italy)

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We present a new geological map at 1:10 000 scale of Ustica Island (southern Italy), founded on original geological and structural fieldwork and stratigraphic investigation carried out during the last decade, combined with a large set of original petrological and geochemical data and the radiometric ages available from the literature. These data have been merged in a revised eruptive and magmatic history of this volcanic island, developed between ca. 737 ka and the last Interglacial Cycle by means of both subaqueous and subaerial effusive and explosive eruptions alternating with phases of marine erosion related to the Middle-Upper Pleistocene sea level high-stands and intense ENE-WSW-trending tectonic activity.
Fieldwork and stratigraphy are based on 25 lithostratigraphic units as the basic units for mapping the distinct rock bodies, combined with 10 lithosomes defining the distinct eruptive centres vents active through time and various unconformity-bounded units (synthems) providing correlations. In particular, five synthems (Passo della Madonna, Timpone Basile, Cala della Madonna, Tramontana, Cala Santa Maria) and the informal Paleo-Ustica unit are subdivided by primary marine and subaerial erosive unconformities, in places associated to tectonic phases. The eruptive and magmatic history of Ustica is then interpreted as the time-stratigraphic succession of five major periods of activity (Eruptive Epochs, thereafter EE 1-5) separated by erosional stages of quiescence and characterized by distinctive eruptive vents and products.
EE 1 (Paleo-Ustica, ~737 ka) comprises hyaloclastites and pillow lavas erupted from an ENE-WSW oriented submarine eruptive fissure at progressively decreasing depth. During EE 2 (Passo della Madonna Synthem, 519-476 ka) effusive and explosive activity occurred in a transitional shallow submarine/subaerial environment (emerging stage) from different vents and eruptive fissures mostly located along the western and northwestern coast of Ustica island. The bulk of the two main stratovolcanoes of the island, namely Mt. Guardia dei Turchi and Mt. Costa del Fallo, was also built during this epoch. After a relatively short period of quiescence, the activity of Mt. Costa del Fallo continued during EE 3 (424-412 ka) with the sub-Plinian explosive eruption producing the Grotta del Lapillo pumices tephra and the effusion of the Timpone Tranchina mugearitic lava flows from the summit crater and lateral centresvents in the NW coastal sector. EE 4 occurred from vents located in the NW sector of Ustica, in the area of Punta Testa del Rosso and Passo della Madonna, producing widespread lava flows that presently crop out along the whole northern coast of the island. A subsequent prolonged period of quiescence is recorded in different marine terraces raised at different elevations up to a maximum of ~100 m asl due to regional tectonic uplift, together with ENE-WSW-trending normal faults with a sinistral horizontal component. Renewed volcanic activity during EE 5 produced the poorly differentiated Na-alkaline pyroclastic products of the Capo Falconiera tuff cone, which was active during the Last Interglacial cycle (~120 ka) interrupting a period of prevailing marine erosion and deposition.
All the Ustica volcanic rocks show a Na-alkaline affinity and range in composition from basalts

to hawaiites and mugearites. More evolved products are represented by the light juveniles of the pyroclastic sequence of Grotta del Lapillo, showing a trachytic composition. Benmoreites are scarce or absent, and a gap is evident in the SiO_2 range 55-60 wt%. The content in incompatible elements in mafic magmas significantly increases from the oldest products of Paleo-Ustica to the most recent products of Capo Falconiera. As a whole, the geochemistry of Ustica magmas suggests that they originated from complex processes, including different degrees of partial melting of a mantle variously metasomatized by the dehydration of the Ionian slab during its subduction, in a general intraplate geodynamic setting.

S2.17- Poster

Palaeomagnetic dating of Holocene eruptions at Tenerife (Canary Islands): Assessing the palaeomagnetic vs. radiocarbon dating accuracy on active volcanoes

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The timing of Holocene volcanic activity of Tenerife (Canary Islands) is poorly constrained and the volcanological framework for this area is still incomplete. Most of the eruptions are dated only by a single radiometric dating, or the ages are simply stratigraphically determined. We apply palaeomagnetism, increasingly used in the last years to date Holocene volcanism, to improve the knowledge of Tenerife volcanic history. We report on the palaeomagnetic dating of nine Holocene eruptions, that produced scoria cones and major lava flows, and we compare our results with those previously obtained by ^{14}C method. Four of the studied eruptions were previously dated by ^{14}C, four only stratigraphically constrained, and one was never dated so far. Concerning the first group, for two eruptions the palaeomagnetic and ^{14}C ages agree, while for the others we obtained older or younger ages than the previous data. Ages characterized by short incertitude age ranges (35 - 545 yrs) were found within the second group. Finally, we provided the first age (789-723 BC) of the Mna Grande eruption. We conclude that palaeomagnetism can be considered an excellent complement to radiocarbon method, because it is applicable on rocks with nearly all compositions and provides higher resolution dating, at least where reliable geomagnetic reference curves are available. The improved framework of the Holocene volcanic activity of Tenerife shows alternating periods characterized by low and high eruptive frequencies, with the last 3 ka characterized by high eruptive frequency and dominated by basaltic eruptions.

S2.18- Poster

Volcanological map of the Somma- Vesuvius Volcano (Italy)

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A new version of the volcanological map of the active Somma-Vesuvius volcano is presented at the 1:20,000 scale. The map is based on 1:5,000 field mapping carried out during the Italian CARG project. Geological data are represented onto a digital terrain model of the volcano, allowing a better visualization of the main morphological, volcanic, and geological features. The legend is organised in four different panels, summarizing the different phases of the volcano and caldera development. The geological survey is based on recognition and description of lithostratigraphic units. The main map is complemented with a table reporting areal distribution and thickness data of tephra fallout and PDC deposits of 20 eruptions with different magnitude and intensity occurred during the last 22 ka of activity of the volcano.
The map and the table well summarize the volcanic evolution of the Somma-Vesuvius volcano, and are propaedeutic to any further studies aimed at improving the scientific knowledge and volcanic hazard assessment of this world-famous volcano. Furthermore, easiness of reading and directness of the message brought by the large amount of geological information are particularly important also for a correct dissemination of the available knowledge on the volcanic area, of absolute relevance for increasing the awareness of the several hundred thousand inhabitants living on the volcano slopes and the nearby plain.

S2.19- Poster

S3. GEOMATICS DISCIPLINES AND THE INNOVATIVE UAV-BASED TECHNIQUE TO RECONSTRUCT THE TOPOGRAPHY AND TO INVESTIGATE ACTIVE VOLCANOES

Conveners:
Marina Bisson (INGV-PI), Fabio L. Bonali (UniMib),
Massimo Cantarero (INGV-OE), Emanuela De Beni (INGV-OE),
Fabio Marchese (UniMib), Joël Ruch (University of Geneva),
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New approaches in lava flow mapping and DEM updating employing innovative technologies

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Etna is one of the most active volcanoes on the Earth. Its eruptions occur both at the summit and from its flanks. Although in the past 40 years, the average interval between flank eruptions has been only about two years, in the last eight years we assisted at almost 60 eruptions and lava flows emplaced. Considering the huge amount of people living on his flanks and visiting the volcano every year the lava flow monitoring for risk mitigation and Civil Protection purposes is one of the fundamental tasks of the Cartographic Laboratory of the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo. Lately, the request for quickly and low-cost cartographic updates has increased, for this reason, it was necessary to find unusual and innovative techniques to perform photogrammetry. The approach we present has peculiarities:

- quick planning and carrying out of surveys,
- low cost
- usage of different sensors.

In particular, we tested the simultaneous use of UAV, high precision GPS, Hi-resolution camera with GPS integrated, a backpack composed by a reality capture sensor platform combines imagery and point cloud and a portable imaging laser scanner. This new tool was tested on the summit crater of Etna and in a lava tube. We have reconstructed a georeferenced 3D model of the Monte Intraleo lava tunnel located along the lower West flank of Etna volcano. The survey was performed with a BLK laser scanner and an Unmanned Aerial Vehicle (UAV). We georeferenced the tunnel dense cloud using the entrance of the tunnel dense cloud obtained with both the UAV and the laser scanner. The different dense clouds obtained after each survey were then elaborated with dedicated software that allow their management and overlap. This experiment demonstrated the possibility to obtain high precision 3D models with the most suitable tools on the base of the target and on the disponibility of the tools. This new photogrammetry approach can be applied in any environment where high-precision 3D reconstruction is required to update the topographical changes and to evaluate volcanological parameters such as area and lava volume effusion rate and so on.

S3.1 - Presentazione orale

UAV-based Structure from Motion techniques applied to volcano-tectonics: an example from active rift in NE Iceland

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In geological studies, data collection and field observation are essential, especially in volcanic terrains affected by ongoing deformation both induced by tectonic and magmatic forces, resulting in an increasing need of an improved geohazard assessment. Unfortunately, these sites are very often characterized by difficult logistic conditions, and thus they are not easily reachable, or their area is too wide to be studied with classical field survey only.
The Structure from Motion (SfM) techniques, combined with the use of Unmanned Aerial Vehicles (UAVs), represent a modern tool to overcome these problems and to collect plenty of geomorphological and structural data also in areas affected by difficult logistic conditions (e.g. lava terrains, active craters, extremely fractured areas). The application of this technique allows to obtain high resolution orthomosaics, Digital Surface Models (DSMs) and 3D models, which can all be used to improve mapping of active Holocene structures, and thus allowing a better understanding of geology and a resulting better geohazard assessment.
We applied this technique in an area of 9 km^2 affected by seismic and volcanic hazard, which is located in the southern sector of the Theistareykir Fissure Swarm (ThFS), an active rift belonging to the Northern Volcanic Zone of Iceland. Such area is characterized by the presence of Holocene lavas (8-10 Ka), affected by normal faults with offset ranging from 0.5 to 12 meters, and by a dense swarm of extension fractures, along which we measured strike, opening direction and dilation.
Our effort has been focused on better defining structures whose origin is related to volcano - tectonics and active tectonics, in order to quantify the present strain field in the southern ThFS by measuring the vertical offset along normal faults and the opening vector along extension fractures, collecting structural data along a total of 546 fractures (comprising 517 extension fractures and 29 normal faults).
The study area has been surveyed with 12 different UAV missions, carried out during two campaigns in summer 2017 and 2018, which allowed to collect a total amount of 8841 photos. Thanks to the SfM workflow, such photos have then been used to reconstruct a high quality orthomosaic with 2.5 cm resolution, and a DSM of the area with 10 cm of resolution. Our results confirmed that the UAV-based SfM technique is convenient and efficient in order to collect a huge amount of structural data in volcanic areas. In fact, the high resolution of the UAV-SfM derived resulting models allowed us to recognize with very high detail all the fractures outcropping in the area, and to collect a total of 1359 structural data on 453 different structural stations along extension fractures, and 36 offset measurements along normal faults, which can be analyzed in order to quantify the present strain field of the area. Finally, we obtained an overall direction of extension of 106.4°N and a stretch of 1.015, suggesting that tectonics and diking work together dictating the present picture of deformation in the area.

S3.2 - Presentazione orale

Achievement of topographic data from drones in volcanic areas, comparison of different methodologies

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This work wants to show the comparison between different methodologies to obtain Digital Elevation Model (DEM) trough UAVs calculating also the errors in the results. In particular, we want to demonstrate which is the better technique to face eruption crises, considering the timing and the reliability of the results. To mitigate the risk associated to an eruption it is necessary as much trustworthiness information as possible in the less time possible. We have overflight a carefully selected area characterized by the presence of a relatively young lava flow easily to reach to allow us to repeat the survey several times if necessary. This area had to be well exposed without vegetation to avoid the problem related to it during the photogrammetric process. The lava flow field had to be included in the area covered by the LIDAR survey of the 2005, used to obtain the summit Etna DEM [Bisson et al., 2008]. We chose this DEM as reference because it was validated with the INGV permanent GPS network.
The studied area is located in the Southern flank of Etna Volcano at about 1800 m a.s.l. and is characterized by the presence of a branch of the 2002-03 lava flow. We performed a survey with Real-Time Kinematic (RTK) UAV positioning several Ground Control Points (GCP) homogenously spread around the lava flow unit. Then we ran the images with Structure from Motion (SfM) Software comparing three different ways of images process: with RTK correction, with GCP, without GCP and RTK correction. The result of this work demonstrates which is the best practice to apply when a lava flow map and a volume estimation request to characterize an eruptive event. For the volume estimation is, moreover, necessary a pre-eruptive surface the most accurate and at high resolution as possible.
Ones the best practice will be find it could be applied in every environmental when a rapid and efficient answer to a natural disaster is requested.

S3.3 - Presentazione orale

Monitoring the morphological changes associated with the 3 July 2019 and 28 August paroxysmal eruptions at Stromboli volcano (Italy) using UAVs

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Resolving morphological changes through time using accurate high-resolution digital elevation models (DEMs) is key to understanding active volcanic processes. Unmanned Aerial Vehicles (UAVs) have recently become a powerful platform for aerial data acquisition of DEMs. They permit a rapidly-deployable, low-cost alternative to classical manned aerial photogrammetry, which is especially useful for large-to-medium-scale landscape reconstruction or detailed 3D surveying of features of interests. In addition, the use of UAVs reduces the exposure of operators to volcanic hazards.
We used UAVs to monitor morphological changes of the Stromboli crater terrace area following the paroxysmal eruptions occurred in the Summer 2019.
The first intense paroxysmal eruptive sequence occurred at Stromboli on 3 July and involved both the North and the Central-South crater areas. The paroxysmal eruption generated an eruptive plume rising 4 km above the summit (924 m a.s.l.) while the incandescent material set fire to vegetation on the flanks of the volcano. Volcanic products from the laterally directed explosions and from the collapse of the external crater terrace generated two pyroclastic flows that traveled down the Sciara del Fuoco (SdF) and for several hundred of meters out to sea. Between 3 July and 28 August, the activity was characterised by lava flows in the Southern sector of SdF and by very intense Strombolian activity by a set of small scoria cones, which had grown around the vents, particularly in the N crater area. The second paroxysmal eruption occurred on 28 August involving again the two crater areas and producing an eruptive column that rose 4 km above the summit. Material from the eruption and from the collapse of the rim of the C-S area contributed to the generation of a pyroclastic flow that traveled again down the SdF and out to sea. Important morphological variations to the crater terrace were evident after the two paroxysms.
Five high-resolution UAV survey campaigns have been performed since May 2019. The aerial images were acquired using two different UAVs, a DJI Mavic 2 Pro and a Wingcopter. Using Structure-from-Motion (SfM) techniques we generated DEMs of the crater terrace area and of lava flows. The presence of the volcanic plume required a further elaboration of the dense cloud. The obtained DEMs have a resolution ranging between 0.2 and 0.5 m. Additional 1 m DEM was extracted from available tri-stereo Pleiades satellite imagery.
The comparison of the multi-temporal DEMs allowed for the evaluation of the height variations due to the 3 July 2019 and 28 August paroxysmal eruptions, for the morphological variations

occurred in the crater terrace as well as for the simultaneous evolution of the lava flows.
The combined use of UAVs and SfM techniques are crucial for improved capabilities to collect frequent and low-cost measures on landscape changes associated with the rapid dynamics of active volcanoes. The data collected during these field efforts and the temporal comparisons of the DEMs represent a fundamental contribution to both volcanic hazard assessment and risk mitigation, and can be used to support civil protection operations.

S3.4 - Presentazione orale

New insights on dyke-induced surface deformation revealed by UAV-based high resolution model

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Understanding the kinematics and origin of structures along active rifts is of paramount importance for both volcanic and seismic hazard assessments. Here we focus on the analysis of surface deformation of a volcanotectonic structure in the Krafla Fissure Swarm, located in the North Iceland Rift, affecting the pre-LGM Hituholar volcano and 12 ka old lava field whose origin is related to magmatic and tectonic activity.
The work has been carried out through the Structure from Motion technique (SfM) applied to UAV surveys, integrated with a lithostratigraphic field survey. The resulting Orthomosaic and Digital Surface Model (DSM) have a resolution of 2.6 and 10 cm, respectively. This zone of deformation is characterised by topographic bulging, parallel extension fractures, and narrow grabens with locally floor uplift, which can be explained as the effect of shallow propagation of a dyke northward from the Krafla magma chamber. In fact, the study area has been interested by northward dyke propagation from the central volcano during the recentmost rifting event, which occurred in 1975-1984 (Krafla fire).
The analysis of the very wide area covered by our UAV surveys indicates that changes in the pattern of surface deformation occurr in correspondence of contacts between deposits with different rheological properties: the transition from very stiff lavas to soft hyaloclastites produces a change from extension fracturing to normal faulting. These structures affect both pre and post-Latest Glacial Maximum units. Moreover, we detected on the Orthomosaic and DSM a series of extension fractures with NE-SW left-lateral and NNW-SSE right-lateral components of motion that are rotated clockwise and anticlockwise respect to the main NNE-SSW graben trend, and extend outward up to about 17 m. We interpret these structures as originated in front of the dyke tip during its propagation and being successively bypassed by the dyke advancement. This dyke propagation process was slowed down in correspondence of the hyaloclastite where the dyke thickened. In case of an active volcanic zone, the comprehension of the surface deformation and of the significance of strike-slip faulting occurrence can help to determine how and where magma is propagating. Thus, these evidences may help to decipher geophysical data and surface structural data during volcano monitoring.

S3.5 - Presentazione orale

Landform monitoring in Pisciarelli (Campi Flegrei) active fumarolic field using UAV photogrammetry

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The combined use of unmanned aerial vehicles (UAV) and digital photogrammetry (DP) represent a rapidly evolving field of technological application allowing geoscientists to obtain very detailed spatial data products that are suitable for rapid mapping and analysis of dynamic landscape processes. Our research is committed to active volcanic areas and is aimed at acquiring time series of digital data for monitoring the geomorphological evolution of relevant volcanic structures. The study is focused on Pisciarelli site, a fault-related fumarolic field located a few hundred meters east of Solfatara crater, Campi Flegrei, Italy. This area is characterized by a consistent soil degassing and fluid emission from vents, mostly ephemeral and hot pools. This degassing activity was episodically accompanied by local seismic activity and by some macroscopic changes such as the appearance of vigorous degassing vents ($T > 110°$ C) and various mud bubbling pools ($T \approx 90°C$). Small explosions probably accompanied these changes. The slopes near the area show relevant instabilities. In order to carry out a short-term monitoring program of the landform changes, caused by the interplay between intensive rainfall and volcanic activity, we made photogrammetric UAV surveys repeated over time and produced ortho-mosaic photos and digital elevation models (DEMs) by using photogrammetry software with computer vision technique, i.e. Structure from Motion technique. The ortho-mosaic photos and DEM data were utilized to create an aerial photo interpretation map and a 3-D map. In this way, we have estimated the area and volume of Pisciarelli fumarolic field and the changes occurred from November 2019.

S3.6 - Presentazione orale

10 years of morphological changes at Mt. Etna volcano by using satellite and lidar data

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The areas characterized by dynamic and rapid morphological changes need accurate, up-to-date topographic data, especially if these areas are populated and contain significant infrastructures. This results particularly true for active volcanic areas such as Mt. Etna (Italy). In the last 15 years, the volcano has been periodically characterized by explosive and effusive eruptions becoming a potential hazard for local residents and hundreds of tourists that visit the volcano itself every day. In this work we present a very high-resolution Mt. Etna Digital Elevation Model (DEM) derived from Pleiades satellite images updated to 2015. The model covers an area of approximately 400 km^2 with a spatial resolution of 2 m involving the summit portion of the volcano and most of surrounding areas. The model is characterized by a vertical and planimetric accuracy of 0.78 m and 1 m, respectively. Comparing such model with the 2005 Airborne LiDAR model it was possible to analyse the main morphological changes and quantify the volume of lava flows emitted from 2005 to 2015.

S3.7 - Poster

From 1876 to nowadays: morphological changes of Somma-Vesuvio by using historical maps and airborne LiDAR survey

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The eruptive history of a volcano can be investigated by analysing the changes of its topography through time. This work presents the morphological evolution of the Somma Vesuvio volcanic edifice from 1876 to nowadays through the reconstruction of topographies derived from historical maps of IGM (Italian Geographic Military Institute) and Airborne LiDAR data acquired during a survey of 2009-2012. We have focused the attention on the caldera zone trying to consider the different spatial resolution and accuracies of the source data. This is a crucial point for comparing several Digital Elevation Models (DEMs) providing quantitative analyses with relative errors estimations. The analyses performed on GIS platform (ESRI environment) allowed to compare four DEMs: three DEMs built interpolating the elevation data digitalized from 1876, 1906 and 1929 IGM historical maps and a fourth DEM obtained processing the original LiDAR raw ascii data stored in lat long coordinates. The comparison among the DEMs was made analysing the crater centroid spatial position, the elevation profiles along 4 directions, and calculating the volume and surface of the Gran Cono edifice. The results permitted to identify some important volcanic deposits related to specific eruptions, highlight morphological changes of the crater area associated to a probable migration of its centroid, and show a general increasing in surface and volume of Gran Cono edifice from the 1876 to nowadays. Since most of the results are in agreement with literature data, the approach here proposed could be adopted for studying the morphological changes of other volcanic areas which past topographies are documented by a large amount of historical cartography.

S3.8 - Poster

Improving the vertical gradients of gravity prediction by locally refining the DEM using drone-flown photogrammetry

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Some 3D or 4D micro-gravimetric surveys and studies require the knowledge and application of true vertical gradient of gravity (VGG). This demand may be associated with reductions of or corrections to observed gravity or its spatiotemporal changes. In the absence of in-situ measured VGG values, the constant value of the theoretical (normal) free air gradient (FAG) is commonly used. We propose an alternative to this practice which may significantly reduce systematic errors associated with the use of theoretical FAG. The true VGG appears to be better approximated, in areas with prominent and rugged topographic relief, such as alpine or some volcanic regions, by a value based on the modelled contribution of the topographic masses to the gradient. Such prediction can be carried out with a digital elevation/terrain model (DEM/DTM) of sufficient quality: resolution of 5 m or better and vertical accuracy at the order of 10 cm, depending on the roughness of the relief. We quantify also the need of improving the VGG prediction at gravimetric monitoring networks for benchmarks adjacent to man-made structures (walls, buildings, etc.). We present the possibility to improve the VGG prediction by locally refining the DEM by drone-flown photogrammetry. The predictability of VGGs in regions of rugged relief was verified by in-situ observations in the Central Volcanic Complex of Tenerife (Canary Islands) and at Mt. Etna (Italy). We illustrate how strongly and sharply the VGG field deviates spatially from the constant value of FAG. We also analyze the sensitivity of the VGG prediction to the resolution and accuracy of the used DEM. Finally, we discuss the applicability and significance of the topo-predicted VGGs in micro-gravimetric studies.

S3.9 - Poster

S4. ADVANCES IN DATA ANALYSIS FOR GEOPHYSICAL METHODS AND MODELLING OF VOLCANIC SYSTEMS

Conveners:
Raffaele Castaldo (IREA-CNR), Luciano Attilio Maria Zuccarello (UGR), Andrea Cannata (UniCt), Flavio Cannavò (INGV-OE), Vincenzo De Novellis (IREA-CNR), Giuseppe Solaro (IREA-CNR)

Insights on pulsating degassing and Strombolian activity at Mt. Etna 2019 tracked with infrasound arrays

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In the summer of 2019, Mt. Etna experienced an intense Strombolian activity -marked by two lava flow episodes- interspersed with intense degassing. During that time, we deployed two 6-element infrasound arrays located at less than 1 km from the active vents of Voragine (VOR) and New-South-East Crater (NSEC). Preliminary analysis using infrasound array processing based on least-square beamforming show how infrasound data can be used to discriminate and track volcanic activity, from background pulsating degassing to individual ash-rich explosions, persistent Strombolian activity, and lava effusion. We also introduce quantitative assessment of uncertainty on the estimates of source backazimuth and apparent horizontal velocity. Results evidence shifts activity from one vent to another with backazimuth errors of less than 2Â°. Moreover, pulsating degassing from different vents is clearly captured by both arrays with waveforms that reminiscent of stronger Strombolian activity with smaller amplitudes. The proposed advanced signal processing presented here stands as a powerful standalone tool to locate and track volcanic infrasound signals with potential for volcano monitoring in near-real time.

S4.1 - Presentazione orale

An algorithm to derive radiance and brightness temperature from multiphase mixtures: the Etna eruption 12/01/2011

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Explosive volcanic eruptions emit and inject into the atmosphere hot pyroclasts and gases. More particularly, the rise of volcanic plumes develops a multiphase cloud as a polydisperse mixture of ash, gases (mainly H_2O, CO_2, and SO_2), and entrained atmospheric air. The injection and fallout of volcanic materials in the atmosphere impacts the atmosphere, the water and the ground around the source, potentially causing hazard and risk to population, aviation, infrastructures, etc. Estimating information on the eruption source parameters, the cloud composition and evolution is essential for volcanic hazard assessments. Remote sensing techniques (ground-based and satellite) have a key role to provide measurements and analysis for potentially dangerous phenomena such as volcanic eruptions. In particular, gas and ash thermal infrared emissions are useful for monitoring volcanic activity and for retrieving diverse features as bulk plume properties, ash particle size, eruption source parameters, optical depth through infrared sensors [Prata A.J., Bernardo C.J., 2009; Prata A.J. et al, 2014; Valade S. et al., 2014; Cerminara M. et al., 2015].
Starting from the study in [Cerminara M., et al. 2015], we present an algorithm for the analysis of electromagnetic emission-absorption volcanic data obtained by ground-based and satellite thermal images. The electromagnetic model is based on the Schwarzschild's equation to describe the plume radiative transfer neglecting the scattering effect. It uses the 3D fields obtained from plume models (e.g. temperature, density, grain size distribution) to get the radiance along optical paths. More particularly, the model estimates the measured average intensity over the typical spectral response of a thermal infrared (TIR) camera and includes the dependence on the wavelength corresponding to the spectral function for the quantities involved, e.g. the absorption coefficient. The radiative absorption properties of the volcanic cloud of the gas-particle mixture have been approximated to homogeneous spheres using the Mie's theory. Moreover, radiometric data has been fitted to properly correlate the infrared radiation with temperatures measured by the monitoring instruments. Then, the presented algorithm is coupled with the 3D ASHEE fluid dynamic model [Cerminara, M. et al., 2016] and applied to the time-average TIR images of the Etna eruption of the 12/01/2011. The synthetic thermal images are then compared with the data from ground-based thermal cameras.

S4.2 - Presentazione orale

DInSAR Analysis and Analytical Modeling of Mount Etna Displacements: The December 2018 Volcano-Tectonic Crisis

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Mount Etna, a 3,324 m high basaltic stratovolcano located on the eastern coast of Sicily (Southern Italy), is the largest active onshore volcano in Europe and one of the best-known and most intensely monitored volcanoes of the planet, implying significant recent progress in the knowledge of its dynamics. The increasing availability of space-borne SAR data provides over time accurate information on the volcano morphology and deformation, particularly during emergency phases, when it is difficult or even impossible to carry out in-situ surveys. Therefore, a fast availability and processing of the SAR data is crucial to help understanding the on-going volcano dynamic.
Since 24 December 2018, a new intense activity has started at Mount Etna and it has been associated with a relevant seismic sequence that culminated with a Mw 4.9 earthquake, occurred on 26 December 2018 on the lower part of the Eastern volcano flank along the Fiandaca Fault and characterized by a strike-slip mechanism.
In this work, we investigate both the volcanic eruption process and the Mw 4.9 mainshock nucleation by using DInSAR measurements, seismological data and analytical modelling. In particular, we first exploit the DInSAR measurements obtained from coseismic SAR data pairs collected by the Sentinel-1 and COSMO-SkyMed satellites from ascending and descending orbits. All of these data have been processed immediately after their availability and have been shared with the National Authorities to manage the volcano crisis. By benefiting from the availability of different orbits (ascending and descending), we retrieve the Vertical and East-West components of the displacements affecting the analyzed area. The obtained results show that the East-West component presents the most significant displacement entities, whose maximum values exceed about 30 cm towards West and about 50 cm towards East close to the volcano summit. In addition, in the area in which the 26 December main shock occurred, maximum eastward and westward displacements of 12-14 cm and 15-17 cm are observed, respectively.
Moreover, we analyse the distribution of the relocated hypocentres in order to identify the involved and activated structures and, to better constrain the geometry and characteristics of the main sources, we extend our analysis by applying a modelling approach based on the analytical method. Therefore, we invert DInSAR measurements to get the combination of seismic and vulcanic sources that better predict the displacement field; non-linear and linear modeling inversions are performed to retrieve source geometries, tensile and shear component distributions. In particular, our model suggests the existence of two volcanic sources, which allow us to retrieve the surface displacements measured through the DInSAR maps and are consistent with the observed seismic swarm.
Furthermore, we exploited the Coulomb Stress Change analysis to understand how the volcanic activity affected some of the seismogenic structures of this area; our analysis clearly reveals that the intrusion encouraged, with a positive loading, the seismic activation of the faults in all the examined areas.
The retrieved results permit to speculate on a possible feedback process for Mount Etna

between volcanic activity and flank movement: most of the flank deformations occurred during the ascent and the emersion of the magmatic dike. However, although the most significant deformations occurred on 26 December along the Fiandaca Fault, also the other faults that border the volcano unstable blocks were induced to move, accommodating the kinematics of the entire deforming sector, toward a new tectonic balance. This picture highlights the potential hazard of Mount Etna flank eruptions for the surrounding towns and villages, because (i) they can produce lava flows that can bury inhabited areas and (ii) they may trigger the motion of faults located in urbanized areas, potentially able to cause seismic events like the one occurred on 26 December 2018.

S4.3 - Presentazione orale

Bayesian inversion of the geodetic data: application on the deformation field of Mt. Etna

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The geometrical and kinematic source parameters of a magmatic source can be characterized by mathematical models like sphere and rectangular. An automatic way to search for these parameters is to invert the observed deformation field while assuming that such kind of models is able to generate the comparable field. Most of the inversion approach iteratively minimize the error of a misfit (between observed and calculated data) function and gives the best fit model. Although, this is highly possible to get the models in the same source volume having equivalent misfit error. This is typically an inherent issue of ambiguity in the geophysical interpretation caused by insufficient spatial resolution of the source volume, discretization of the continuous field and highly noisy geodetic data. An effective way to discard these non-realistic models or in general to address the issue of non-uniqueness is to use a-prior information in the inversion algorithm. Nevertheless, the obtained model parameters are the optimal solution, which fits adequately the observed data and always have some degree of uncertainties. However, we use the Bayesian inversion for estimating the uncertainties associated with each model parameters. This is basically a Markov Chain Monte Carlo (MCMC) method for sampling the posterior probability density function (PDFs) of the source model. MCMC draws the samples from the defined prior distribution iteratively and accept (or reject) the samples based on the assigned probability through the ratio of likelihood value. Since, it is possible to incorporate the standard error of the data in likelihood function, the samples of model parameters take into account the noise present in the observation. There are two samplers which is widely used in the framework of MCMC algorithm: Metropolis-Hasting algorithm and Hamiltonian Monte Carlo (HMC). In this work, we show the application of both the samplers on the GPS data recorded on the INGV network on Mt. Etna. The only constrain we used is to provide the limits (or bounds) to the search space for each parameter. The algorithm samples from the uniform prior distribution within the given bounds, often called truncated uniform distribution. However, MCMC algorithm also gives opportunity to pass a reference or starting model with an assumed mean and standard deviation. Then, the algorithm starts from the reference model and update it in each iteration in order to further check the probability of acceptance. We searched by this inversion approach the model parameters of a dike type source in order to model a magmatic intrusion. Though, we first show the results of the synthetic examples simulating a real case scenario (pre to post scenario) and then apply it on the 2008 and 2018 eruption of the Mt. Etna. We then conclude by comparing the results obtained by the classical inversion approach (pattern search algorithm: PSA) with those obtained by Bayesian inversion. We found the resulted posterior distribution of the parameters are more informative compare to a single best fit model, which explains the overall tendency of the source distribution that can generate the same data. In this case, the results give more confidence to the interpreter and to incorporate more geological and physical information in order to reach the final source model.

S4.4 - Presentazione orale

Advantages and Pitfalls of Pattern Recognition Techniques: the Importance of A-posteriori Analyses

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The application of data-driven approaches to large and complex data sets is an intriguing issue, even though the results must be revised with a critical attitude. For instance, consider a diagnostic tool providing hints for a serious disease, or for anomalous conditions potentially indicating an impending natural risk. The user of such a tool needs high accuracy as well as a small percentage of false positives that can ruin the diagnostics. Receiver Operation Curves (ROC) can help us to find a reasonable compromise between the need of accuracy of the diagnostics and robustness with respect to false alerts.
In multiclass problems success is typically measured as the score for which calculated and target classification of patterns matches at best. A high score does not automatically mean that a method is truly effective, for instance, when a random guess leads to a high score as well. Among others, the so called "Kappa Statistics" is an elegant way to assess the quality of a classification scheme. We present case studies demonstrating how such a-posteriori analysis helps corroborate the results.
When an approach does not lead to the desired success, a sound a-posteriori analysis on the reasons for the failure may provide interesting insights into the problem, such as an inappropriate definition of the targets, inadequate features, etc. Often the problems can be fixed just by adjusting some choices. Sometimes a change of strategy may be necessary in order to achieve a more satisfying result. In example applications of pattern recognition techniques, we highlight the pitfalls arising in particular from ill-defined targets and unsuitable feature selections.
The validation of unsupervised learning leaves open questions as yet. Some formal criteria (e.g. Davies Bouldin Index, Silhouette Index) are available for centroid-based clustering where a unique metric valid for all clusters can be defined. Difficulties may arise when metrics are defined individually for each single cluster (e.g, Gaussian Model clusters, adaptive criteria) as well as using schemes where centroids are essentially meaningless, as they are in density based clustering. In these cases, users are better off when asking themselves whether a clustering is meaningful for the problem in terms of physical characteristics of the clusters. In our presentation we discuss the problem of choosing the number of clusters in cases in which formal criteria are not applicable. We further show how the identification of groups of patterns may help the identification of elements which have a clear physical meaning, even when strict rules for assessing the clustering are not available.

S4.5 - Presentazione orale

Detection of magnetization contrast for Tyrrhenian seamounts through Poisson's analysis, independent on the total magnetization direction

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Volcanic systems are nowadays characterized by analyzing several kinds of information related to different disciplines of Earth Sciences. Among these, geophysical data represent a good tool to achieve the physical properties of the volcanic edifices, especially because they allow avoiding the issues related to the in-situ samples collection. Indeed, conditions for rocks sampling are not always suitable, such as for the seamounts detection, where, indirect investigations are preferable. In these cases, potential fields data analysis represents the best choice since they can be measured at levels different from the topographical surface.
In this scenario, we use gravity and magnetic field data to detect about the physical properties of seamounts. In particular, we perform a combined analysis between the considered anomalous fields through the Poisson's theorem by retrieving the density and magnetization distributions for the Tyrrhenian seamounts.
The Poisson's relation represents a valid tool to reach this purpose: based on the mathematical similarities between the directional derivative of the gravity and the magnetic fields, this relation allows retrieving the magnetization-to density ratio through a combined analysis of the measured anomalies [Garland, 1951].
Currently, the Poisson's relation is mainly exploited by comparing the pseudogravity-transformed magnetic anomalies and the gravity anomaly, or by considering the reduced to the pole magnetic data and the first-order vertical derivative of the gravity field. Unfortunately, both the approaches require the knowledge about the source total-magnetization parameters, which are crucial information to perform the pseudogravity and the reduction to the pole procedures correctly. However, remanent magnetization features are rarely available, and so they are assumed to be equal to those related to the total induced magnetic field; this assumption can lead to wrong interpretations of the analyzed dataset.
For this reason, we here propose other applications of this relation by using different magnetic field transformations. In particular, we use and compare the total gradient and the module of the magnetic field with the second- and first-order vertical derivatives of the gravity data, respectively. This approach is simpler because both the proposed transformations are mostly independent from the remanent magnetization direction.
Specifically, we first perform several synthetic tests by considering the procedure proposed by [Chandler et al., 2001], employing a moving-data window in order to perform a multisource analysis; the best window size is chosen according to these simulations.
Then, we analyze the anomalies related to several seamounts in the Tyrrhenian Sea; since these volcanic edifices are not always characterized by structural homogeneity, we restrict the analysis to its homogeneous sub-parts.
Finally, we retrieve the magnetization contrast values for the analyzed seamounts by considering suitable density contrast values.

S4.6 - Presentazione orale

New approach for the volcanic source characterization: geometrical constraining by using edge-detection methods

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In the last decades, the increasing development of the remote sensing technologies has allowed a better characterization of the volcanic systems and their processes. In particular, the analyses of the ground deformation, acquired both from remote and proximal platform (e.g., DInSAR measurements and GPS data), have improved the modeling of deep and shallow magma reservoirs; this kind of study represents a key task for scientists since it gives crucial information for the hazard evaluation during the monitoring activities of a volcanic system.
Currently, the parametrization of active volcanic deformation sources is performed by employing the optimization and the inversion procedures, which provide a physical and geometrical model of the analyzed volcanic source. Nevertheless, their results strongly depend on the available a priori information and on the considered assumptions about the physical scenario; therefore, they do not guarantee to have a single and stable solution. Moreover, these procedures do not allow a multi-source unrest analysis, which can occur for complex volcanic systems.
In this framework, we show the advances about a new modeling strategy, which is different from the most used above-mentioned ones. The considered approach is based on the use of edge detection-methods for exploiting the large amount of data recorded by DInSAR technique in order to characterize the volcanic bodies responsible of the observed ground deformation field. In particular, this methodology allows the estimation of the source geometrical parameters, such as its depth, horizontal position, morphological features and horizontal sizes, by using Multiridge [Fedi et al., 2009], ScalFun [Fedi et al., 2007] and Total Horizontal Derivative (THD) [Blakely, 1996] methods. Specifically, their validity has been proved for modeling the point-spherical source independently from the physical features of the source (such as its pressure variation), the physical-elastic parameters of the medium (e.g., the shear modulus, lame costant, poisson ratio) and low signal-to-noise ratio of the considered dataset [Castaldo et al., 2018]. Furthermore, the advantages of the Multiridge method during the study of complex multi-source cases has been shown by [Barone et al., 2019] and the usefulness of the THD technique to detect volcanic structures for deforming calderas by [Pepe et al., 2019].
We use Multiridge and ScalFun methods in order to detect and analyze different types of volcanic bodies; we show how to extend the proposed methodology from the hydrostatic-pressure point source [Mogi, 1958] to the others, passing through the tensile-point one [Okada, 1985]. In particular, we mainly take into account two volcanic source analytical models: the rectangular tensile-fault [Okada, 1992] and the prolate spheroid [Yang, 1988], commonly used to approximate sills and dikes, and pipes, respectively. Specifically, we first perform a study about the physical and mathematical features of the considered models. Then, we apply Multiridge and ScalFun methods to the synthetic vertical and E-W components of the ground deformation field produced by both source models. During this step, we carefully point out the advantages and the limitations which could characterize these analyzed cases, showing how to solve critical aspects related to the use of the proposed methodology. We especially focus on the sill-like source, for which the edge detection filters provide very satisfying results. Finally,

we jointly exploit the use of Multiridge, ScalFun and THD methods to analyze the ground deformation pattern of Fernandina volcano (Galapagos archipelago); we detect the geometrical parameters of the deformation source by examining the vertical and E-W components of the deformation acquired by the COSMO-SkyMed satellite constellation during the 2012-2013 time period.

S4.7 - Presentazione orale

Integration of geodetic, seismological and historical data to characterize seismogenic structures: the example of Ischia Island (Southern Italy)

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The island of Ischia, located in the Gulf of Naples, represents a peculiar case of resurgent caldera in which volcano-tectonic earthquakes, with low magnitude, generated large damages and, such as in the case of 4th March 1881 (Imax 8-9 MCS) and 28th July 1883 (Imax 10-11 MCS) earthquakes, catastrophic effects. Both events struck the northern area of the island, similarly to the recent 21st august 2017 earthquake. With about 65,000 inhabitants, Ischia is a popular touristic destination for thermals baths, hosting more than 3,000,000 visitors per year, thus it represents a high seismic risk area. Assessing its seismic potential appears a fundamental goal. To this end, the characterization of the source of the high-damaging earthquakes and the estimate of the magnitude of historical events are crucial. We report a first comparative analysis between the results of the geodetic and seismological data analysis for the 2017, Md=3.9, Casamicciola earthquake and those obtained for the 1881 and 1883 earthquakes from the macroseismic data. The results allowed us to assess the location, as well as the possible dimension and the related-maximum magnitude of the northern seismogenic structure of the island.

S4.8 - Presentazione orale

A feasibility study on the near real-time calculation of the complete seismic moment of the Etna seismicity: application to the earthquakes occurred during the December 2018 eruption

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In a volcanic area, seismicity is characterized by different types of seismic signals, due to the complex interaction between tectonic stress and volcanic dynamics. Referring to the Etna volcano, seismicity mainly consists in earthquakes associated with the fracturing processes of the rocks and seismic signals mainly caused by fluid dynamics (i.e tremor, LP and VLP events).
Complete Seismic Moment Tensor computation allows to a complete definition of the seismic source through the inversion of the waveforms recorded by the seismic stations. It permits to calculate not only the seismic source Double Couple component (DC), which allows identifying the nodal planes of the focal mechanism but also the non - DC components. Among the latter, the Compensated Linear Vector Dipole (CLVD) component can be indicative of the generation of lenticular cracks and fluids dynamics, while the volumetric component (ISO) is an indicator of the volume variations due to explosions or implosions.
INGV routinely computes real-time automatic seismic moment tensor solutions in Italy for Ml greater or equal to 3.5 earthquakes. In this case, the implemented algorithm (TDMT, Dreger et al., 2003), widely employed in many observatories around the world, it is applied mainly to study the DC component of the moment tensor, and the ISO component is constrained to zero. However, for seismicity in a volcanic environment, retrieving the non-DC component is important since it can provide useful insights into the understanding of the source origin and to evaluate the role of magma in the generation of earthquakes. Therefore, it would be interesting to compute the full moment tensor and to tune the algorithm for this special area.
To achieve our goal, we applied the TDMT algorithm to 10 earthquakes with Ml greater or equal to 3.5 occurred in the Etna volcano area during the December 2018 eruptive episode. To calculate the moment tensor, we used different velocity models and station configurations to account for the peculiarity of Etna volcano seismicity and we tested the robustness of the retrieved non-DC components. Finally, the obtained focal mechanisms have been compared with independent estimates of fault plane solutions computed by the first polarities analysis.

S4.9 - Poster

A machine learning framework to produce high-quality seismic data catalogs

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Active volcanoes produce sheer volumes of seismic data that require robust data processing pipelines. Over the recent years, machine learning has arisen as a successful framework in the detection and classification of volcano-seismic signals. Due to the big amount of seismic data acquired by volcanic observatories on a daily basis, manual supervised detection and classification carried out by experts has become a challenging tiresome task. Therefore, it is fundamental to equip the geophysics scientific community with advanced, state-of-the-art processing tools to analyze seismic datasets at a swift pace while keeping minimum complexity. We present a new open-source framework designed to support supervised and unsupervised volcano-seismic data analysis, named PICOSS (Python Interface for the Classification of Seismic Signals). This highly-modular framework, permits (a) Segmentation and classification of seismic events through unsupervised learning procedures, (b) exploration and labeling of raw seismic streams using manual approaches, and (c) automatic picking routines. The implemented modules can select from an algorithmic pool, including deep neural networks and spectral analysis, to annotate large-scale volcano-seismic data catalogs. PICOSS' simple and friendly graphic user interface makes it easy to use both for monitoring to academic purposes.
In this presentation, we demonstrate practical use cases of PICOSS software on Etna, Colima and Montserrat volcanoes. A high-quality dataset is generated and compiled into a standard format using automated machine learning procedures. PICOSS is actively maintained and employed to produce the datasets for the KNOWAVES project (TEC2015-68752) and VOLCANOWAVES (Marie Sklodowska-Curie Grant Agreement no 798480). This research is funded by VOLCANOWAVES project the European Union's Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Grant Agreement no 798480, and by TEC2015-68752 (KNOWAVES, MINECO/FEDER).

S4.10 - Poster

Analyses of ground tilt associated with ordinal explosions and lava effusion in 2014 at Stromboli

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Stromboli volcano is characterized by persistent activities of Strombolian eruptions at summit craters. Furthermore, these normal activities are frequently interrupted by lava effusions (i.e. 2002, 2007, 2014 and 2019). We performed a temporal tilt observation at Stromboli from May 2014 to June 2015 to investigate the ground tilt in detail. The period is characterized by inflation-deflation ground tilt cycles associated with the ordinary explosions and a deflation tilt due to lava effusion occurred on August. In the present study, we analyze the tilt record to estimate the possible pressure sources. We used 5 tilt stations at a distance of <1 km from the active craters. We picked more than 2,000 ground tilt events and extracted tilt amplitude, azimuth and duration. We used tilt vectors averaged for 680 events recorded in the first half of July to estimate a pressure source of the ordinary explosions. Tilt vectors of the deflation during the lava effusion is almost same as the ordinary explosion. Best solution for source parameters was estimated by using FE modeling considering topography of Stromboli volcano. As a result, the size and position of the source for the ordinary explosions and the lava effusion is almost identical and located within a source volume of 200x100x500 m with a centroid at 500 m a.s.l beneath the summit craters. We suggest that ground tilt is generated by the same pressure source, which is basically consistent with the picture of a shallow magma storage inferred from the analysis of temporal evolution of lava effusions occurred in the last 35 years.

S4.11 - Poster

Automatic detection algorithm of rockfall activity based on single seismic station reveals the link between flank instability and volcanic processes

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Stromboli volcano has such a distinctive steep slope, the Sciara del Fuoco, which is very unstable and characterized by moderate rockfall episodes up to extensive landslides. Tracing a long-term distribution of gravitational mass movements, compared to other geophysical parameters, is therefore a key factor in detecting flank instabilities in relation to changes in volcanic activity. Rockfalls and landslides have a distinctive seismic signal, both in time and frequency domain, that could be used to identify them and to analyse their timing and seismic properties such as duration, amplitude, and energy. A new automatic rockfalls detection algorithm, based on a multi-frequency analysis and waveform pattern recognition, is presented and applied to seismic data. The algorithm is capable of recognising signals associated with rockfalls and landslides from seismic signals produced by other volcanic and tectonic sources, with a reliability of 96%. The method was applied to the seismic data acquired from 2003 onwards at Stromboli volcano, thus leading to the analysis of the time series of rockfall distribution over the past 15-year period. It was found that seasonal variations affect the ordinary low energy rockfall activity, while more voluminous rockfalls are related to major changes in the volcanic activity. In particular, high energy events are clustered during periods of strong explosive activity and those preceding the onset of effusive eruptions. This is probably due to the overload of the ejected material and/or the deformation exerted by dike intrusion. We have focused our attention on the analysis of rockfall distribution during period of transition from explosive to effusive regimes finding that an intense swarm of high energetic rockfalls can be considered as precursor of magmatic intrusions and marks the beginning of a flank instability state.

S4.12 - Poster

Automatic Low Frequency seismicity classification using Machine Learning approach

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Low Frequency (LF) seismicity plays an undoubted role in understanding the unrest state of a volcano, due to his strictly link with the magmatic dynamics within volcanoes. Besides, LF waveforms vary depending on the source position and/or source mechanism, and in-depth knowledge of LF waveforms distortion and temporal variation is crucial for volcano activity monitoring. Based on the high occurrence in time of low frequency seismic events acquired by the volcanic observatories, a reliable automatic recognition system must be implemented in whatever real-time volcanic surveillance system to perform correct data analysis.
Aimed to these purposes, we performed a set of automatic processing tools to characterize LF activity at two volcano scenarios, Etna and Colima volcanoes. We design a Machine Learning (ML) architecture based on supervised classification, in order to build a predictive model from our dataset of labeled observations.
The predictive model is obtained through (i) signals detection, (ii) feature extraction of the signals in time and frequency domain, and (iii) the use of an automatic classifier to train the model. Finally, we have clustered LF events into different families allowing us to identify different temporal evolutions for each LF family, which were not recorded continuously throughout the period under study. We suppose that the waveforms change and their different time occurrence can be justified by structural and/or source mechanism modification in the plumbing system, caused by the eruptive activity occurred at the volcanoes.
The proposed approach will open an attractive perspective toward the application of ML algorithms in seismo-volcanic monitoring and forecasting.
This work is supported by the following research projects: TEC2015-68752 (KNOWAVES, MINECO/FEDER); VOLCANOWAVES European Union's Horizon 2020 Research and Innovation Programme Under the Marie Sklodowska-Curie Grant Agreement no 798480; MINECO Research Grants Jose Castillejo CAS17/00411 and CAS17/00154.

S4.13 - Poster

Automatic S-phase picking for volcano-tectonic earthquakes using spectral dissimilarity analysis

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We present an S-phase picking algorithm for volcano-tectonic earthquakes, based on the changes of frequency and amplitude expected in the plane transverse to the ray direction at S-phase arrival. A measure of these changes, called spectral dissimilarity, is proposed. Picking is performed in a particular waveform transformation that underlines such variations foreseen: horizontal instant power. Then, the algorithm provides a measure of its reliability, grounded on the low or high fluctuations of the picking instant obtained when applied to other horizontal components of the seismogram. This quality evaluation is a useful tool to differentiate picking results depending on their application, or to give them different weights when used as input for seismic tomographies. Two main results of the experiments performed are remarkable. Firstly, the algorithm works satisfactorily for volcano-tectonic events in spite of the difficulties that these low magnitude and shallow events present. Secondly, the automatic picking-quality provided (coherent with quality evaluation performed by human experts) permits to distinguish reliable from non-reliable pickings, and therefore select a quality threshold depending on the needs.
Experiments are performed to test the algorithm with a challenging database of volcano seismic earthquakes from Mt. Etna, carefully picked and labelled by a human expert. The technique is compared to two well-known S-phase pickers: one based on the damped predominant period analysis, and a second one based on polarization and kurtosis rate analysis. The algorithm improves these techniques for the particular scenario of volcano-tectonic earthquakes, providing interesting results and possibilities of application.
This work is supported by the following research projects: TEC2015-68752 (KNOWAVES, MINECO/FEDER); VOLCANOWAVES European Union's Horizon 2020 Research and Innovation Programme Under the Marie Sklodowska-Curie Grant Agreement no 798480.

S4.14 - Poster

Deriving volcanological parameters from seismo-acoustic signals: case of study of the 2013 lava fountains at Mt. Etna

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To date, in order to mitigate risks during explosive eruptions, the volcanological community uses models to forecast the area that could be mostly covered by volcanic ash dispersal and tephra fallout. Those models need meteorological weather forecasts and eruption source parameters that define the volcanic activity and are obtained using remote sensing systems as surveillance video cameras. However, often the video-surveillance does not allow to reliably monitor the volcano activity when for example, cloud coverage prevents directly observations of the summit area. Mainly for this reason, the objective of this work is to investigate the relationships between the seismic-acoustic parameters (volcanic tremor and infrasonic signals) and volcanological parameters (e.g. height of the lava fountain), in order to obtain a model that allows us to estimate in real time some volcanological parameters. We processed data from three different lava fountains of Mt. Etna (Italy), that occurred between April and November 2013 at the New South-East Crater (NSEC - located about 3300 m a.s.l.), through the aid of a software implemented in Matlab®. Initially, we carried out an analysis of volcanic tremor and infrasonic signals, recorded by a seismic-acoustic station of the Istituto Nazionale di Geofisica e Vulcanologia Osservatorio Etneo - Sezione di Catania (INGV-OE), to estimate the variation of amplitude and released energy with time. Subsequently, we processed videos acquired by two thermal cameras (EMOT and ENT) of INGV-OE located in Nicolosi and Montagnola and estimated the variation of lava fountain height with time. Finally, the seismic-acoustic data were compared with volcanological data, with the aim of deriving a model that allows us to estimate the height of the lava fountains starting exclusively from a seismic-acoustic dataset.

S4.15 - Poster

Detection of multi-term periodicity from secular effusive activity: the case of Santiaguito lava dome (Guatemala)

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The eruptive activity at Santiaguito volcano (Guatemala) is continuous since its inception in 1922 and it is characterized by effusion of blocky domes and lava flows, punctuated by moderate explosions of steam, small pyroclastic flows, rockfalls and frequent lahars. Lava flows have become increasingly dominant since the 1960s, with some extending over ~ 3 km from the vent. In the present study, we reconstructed the discharge rates from 1922 to 2019 combining new satellite thermal data integrated with published discharge rate data. In particular, for the recent period (2000-2019) we analysed the thermal energy spectrum of Santiaguito dome through the Middle Infrared Observation of Volcanic Activity (MIROVA) hot-spot detection system [Coppola et al., 2016]. Based on the near-real-time (NRT) analysis of the MODerate resolution Imaging Spectro-radiometer (MODIS), this system is able to detect thermal radiation emitted from volcanic sources. By using two different methods, such as the Discrete Fourier Transform (DFT) and the Morlet wavelet analysis, we found a multi-term cyclic behaviour during the last century of almost continuous eruptive activity. For the last 20 years, the methods showed good agreement with long- (ca. 1 year), intermediate- (ca. 6 months) and short- term (ca. 120 days) periodicities, considering quasi-daily and weakly means of discharge rates. As for many others lava dome-forming volcanoes, the cyclic behaviour with different periodicities can be related to the different sub-regions of the magma feeding system. Our preliminary findings can provide new interesting insights on the non-linear cyclic behaviour of Santa Maria volcanic system, useful for a general framework for the comprehension of eruptive behaviour of andesitic volcanoes.

S4.16 - Poster

Infrasound signal detection using multi-band analysis

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Infrasound has become an important tool for volcano monitoring during the past decade, owing to its ability to detect and characterize explosive volcanic activity with high temporal resolution. The amount of data recorded by volcano observatories makes their manual analysis a challenging, frequently unfeasible, task. The implementation of automated tools to address this challenge is, thus, vital for effective monitoring operations. Here, we present an advanced approach for acoustic infrasound event detection that overtakes the application of the traditional short-term average/long-term average (STA/LTA) algorithms, which have shown limitations when applied in volcanic environments, or more generally to signals with poor signal-to-noise ratios. Taking advantage of advanced signal processing techniques, in combination with *a-priori* knowledge of recorded explosions, we have implemented a robust infrasound detector, based on adaptive multi-band processing. The algorithm is based on the characterization of the shape of the explosion signals, their duration, and frequency content. We have tested the goodness of our algorithm by using dataset acquired by two different volcanoes: Santiaguito (Guatemala) and Etna (Italy) volcanoes. Our encouraging results suggest that real-time implementations of detection algorithms could be crucial to improve existing infrasound datasets and ultimately, increase our ability to monitor unrest at active volcanoes.

S4.17 - Poster

Seismic Tomography of Southern Tyrrhenian by means of teleseismic data

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The topic of my work is a seismic tomography which has as object the investigation of Southern Tyrrhenian. This tomography was obtained by means of inversion of teleseismic data and an iterative computation of them to obtain the so-called residual that is the difference between the observed travel times and these theoretical travel times. The final tridimensional velocity model corresponds to that having the minimum residual. The entire process of operation of a seismic tomography is very relevant in order to investigate subduction zones. This is the case of the Southern Tyrrhenian oceanic back-arc basin. The subducting lithosphere has been mostly consumed along the Tyrrhenian-Apennine system has been consumed with the exception of the Calabrian arc sector. The Ionian subduction is documented by several previous works, included local seismic tomographies that have discovered the presence of high seismic velocity body beneath the Calabrian zone. The new seismic tomography, which derived from the inversion of travel times of teleseismic ray paths, travelling in the upper mantle at high depths. This kind of 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. Consequently, grid nodes are 10 in depth, 17 in longitude and 28 in latitude. I have implemented six iterations of this code, stopping it when there are not more significant changes in RMS and in variance of theoretical traveltimes. 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 respectively of 14°, 15°, 15.5° and 16° and 4 WE vertical sections at fixed latitude respectively of 39°, 39.5°, 40° and 40.5°. Finally, I have made 3 transversal sections, choosing as traces the same illustrated by Montuori et al. [2007], for their teleseismic tomography of Southern Tyrrhenian. This work, together with contributions of Chiarabba et al. [2008] and Calò et al. [2012] is a fundamental landmark for the comparison of the results. 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. In the depth interval from 250 km to 400 km, there are two impressive high velocity areas in northern Sicily and along southern Campania with a value of 0.3 km/s, separated by a low velocity area (LVA) along the Calabrian arc and the Aeolian Islands in the range [0.4 - 0.6] km/s. Extensions of HVAs and LVAs previously mentioned have been estimated by means of vertical and transversal sections. This evidence could be interpreted as the effect of a three-dimensional circulation of astenospheric flow provoked by slab roll-back. A new evidence from the tomography is the presence of a LVA in the [250; 400] km depth interval with an extension of 100-150 km that practically splits the Tyrrhenian slab into two parts, in Neapolitan region and in the southern Calabria-northern Sicily region. This evidence is partially in agreement with Chiarabba (2008), that in in his work showed the presence of a "window slab" with an extension of 150 km, in a depth interval included between 100 and 300 km of depth. The presence of this "window slab" could be interpreted as a tear in which unperturbed mantle insert itself.

S4.18 - Poster

Tilt and HR-GPS as powerful tools for volcano monitoring and surveillance: The May 29 - June 5, 2019 eruption at Mount Etna

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Following an increase of volcanic tremor in the late evening of 29 May 2019, a new eruption started in the early hours of 30 May at Mt. Etna. In particular, at 01:20 UTC the opening of an eruptive fissure was observed at the northern base of the New SE Crater (NCSE), at about 3150 m asl with a mild explosive activity and lava flow towards Valle del Bove. At 03.35 UTC, a second eruptive fissure opened on the southeastern base of the NCSE at an altitude of about 3050 m asl, with an emission of a lava flow that expanded along the Valle del Bove toward Serra Giannicola Grande.
In the following days the activity stabilized and the two different lava flows were simultaneously poured from the two fissures until afternoon of 1 June when the lava flow generated by the northern eruptive fissure was no longer fed. Lava flow of the southern one reached the altitude of 1700 m asl and since June 4, emission rate at the fissure progressively decreased and stopped on June 5.
At present, the Mt. Etna permanent tilt network consists of 17 borehole instruments and a long-base device. Over the last ten years, INGV improved the network through installation of sensors at greater depth: currently six stations are 10 meters deep and eight are at 27-30 meters including three summit stations. The deeper stations use biaxial self-leveling instruments with high precision (10-8 - 10-9 radians), electrolytic bubble sensors for measuring the angular movement and magnetic compass that are able to detect tides.
With its 39 permanent stations the Etnean GPS network is one of the largest deployed in an active volcano. For surveillance purposes, most of the stations are processed in real-time at high-rate (1Hz) by using the epoch-by-epoch algorithm of Geodetics ® RTD software package.
Tiltmeters recorded changes during the May 29 - June 5, 2019 activity. In particular, the summit station of Cratere Del Piano (ECP) showed the largest changes that started since 29 May at 16:45 UTC, about two hours before the volcanic tremor increase.
ECP data are very useful to outline the processes occurred before the opening of the fissure (between the afternoon of 29 May and the first hours of 30 May).
Minor tilt changes (less than 1.0 microradian) were measured at several stations located at medium altitude. These changes generally started at about 03:00 UTC (after the fissures opening) and ended at about 23:00 UTC on 30 May. Changes with roughly the same times have been also recorded by high frequency GPS (HR-GPS) data. Tilt and GPS testified a phase of deflation of the edifice that has accompanied the lava flows during the first 20 hours.
Using an INGV-OE software package, we inverted these variations (tilt and GPS) in order to image the observed ground deformation pattern under conditions of a homogeneous, isotropic and elastic half-space. We obtained a deflating source located at a depth of about 1300 m asl and about 1.0 km SW respect summit craters.
Regarding the model variation in volume, we estimated values smaller (less than a third) than the ones estimated by drone surveys ($3.5*10^6 m^3$, De Beni personal communication) that however considers the entire period of activity. Tilt record a depressurization process until the 23:00 UTC of 30 May, while the successive lava emissions (May 31-June 4) occurred without ground deformation.

In conclusion, highly sensitive tilt instruments, with accurate and deep installations may furnish, together with HR-GPS data, important signals to detect and better understand volcanic processes.

S4.19 - Poster

S5. MULTIDISCIPLINARY INVESTIGATIONS FOR THE DEFINITION OF STRUCTURE AND DYNAMICS OF ACTIVE VOLCANIC SYSTEM AND CONTROL IN ERUPTIVE STYLE

Conveners:
Roberto Isaia (INGV-OV), Mariangela Sciotto (INGV-OE), Andrea Cannata (UniCt), Maria Giulia Di Giuseppe (INGV-OV), Eugenio Privitera (INGV-OE), Antonio Troiano (INGV-OV), Stefano Vitale (UniNa)

An Integrated Geophysical Approach to Track Magma intrusion: The 2018 Christmas Eve Eruption at Mount Etna

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On 24 December 2018, a violent eruption started at Mount Etna from a fissure on the southeastern flank. The intrusive phenomenon, accompanied by intense Strombolian and lava fountain activity, an ash-rich plume, and lava flows, was marked by significant ground deformation and seismicity. In this work, we show how an integrated investigation combining high-rate GPS data, volcano-tectonic earthquakes, volcanic tremor, infrasound tremor, and infrasound events allows tracking the magma intrusion phenomenon spatially and temporally with unprecedented resolution. Moreover, it enabled showing how the central magma column lowered as a response to the flank eruption and to constrain the zone of interaction between the dike and the central plumbing system at a depth of 2-4 km below sea level. This is important for understanding flank and summit interaction, suggesting that explosive summit activity may in some cases be driven by lateral dike intrusions.

S5.1 - Presentazione orale

Dynamics of the boundaries of the Mt. Etna sliding flanks: the multidisciplinary study of the Pernicana and Trecastagni faults

INGV OE-OV Etna-Volcano Deformation Group*

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The complex interaction between regional stress, gravity forces and dike-induced rifting of Mount Etna, seems to have a role in the eastward movement of the Mt. Etna eastern flank. In this context the Pernicana and the Trecastagni-Tremestieri Fault systems identify the northern and southern boundaries of the unstable sector.
The Pernicana fault system is formed by discrete segments, arranged in a right stepping en echelon configuration, of a left-lateral shear zone that dissects the north-eastern flank of Etna. The kinematics of this system is related to shallow seismic crises (M=4.0) occurring along the western segment, with dip-slip displacement and left-lateral components. The eastern segment, ESE trending, shows only aseismic creep with purely left-lateral displacement.
The Trecastagni fault is a NNW-SSE tectonic structure developing on the lower southern flank, characterized by evident morphological scarps and normal and right-lateral movements that directly affect roads and buildings. This fault is affected by continuous creep with episodic accelerations accompanied with shallow seismicity.
The dynamics of these faults has been analysed by a multi-disciplinary approach with terrestrial and satellite ground deformation data. Terrestrial data consist in levelling across both faults and extensometers record on the Trecastagni fault. Satellite data consist in InSAR data and GPS surveys on wide and local networks.
The levelling route on Mt Etna is 150 km long and consists of 200 benchmarks. Part of the levelling route crosses the Pernicana fault, at an altitude of 1500 m asl and 700 m asl (Rocca Campana). Measures on this network started on eighties and provide a high detail on vertical kinematics allowing strong constraints in source modelling of slip episodes. A levelling network has been installed on 2009 across the Trecastagni fault; the surveys show a mean vertical slip rate of about 10 mm/y and episodic acceleration on short segments of the fault, with displacements of almost 30 mm.
The monitoring of the Trecastagni fault is also performed by two continuous wire extensometers and a system for periodic direct measurements across the fault in its central and north-central sectors. Each extensometer is equipped with a data-logger programmed for 48 data/day sampling, storing displacement and ground temperature. The two stations measure the relative displacements perpendicular to the fracture. Data recorded by extensometers highlight an opening trend of about 2-3 mm/year with some acceleration leading up to more than 2 mm in 15 days at the end of 2009.
Both faults show clear traces on SAR interferograms and Persistent Scatterers (PS) time series. InSAR data allows tracking the path of the Pernicana fault from its connection to the NE rift to the coastline; the eastwards motion abruptly disappears north of the fault, producing a left-

lateral transcurrent kinematics at a rate of about 20-30 mm/y. The Trecastagni fault shows a main vertical kinematics, with an evident downthrow of the eastern side at a rate of about 4 mm/y. Subsidence increase eastwards away from the structure, reaching a maximum rate of almost 10 mm/y. The fault produces a minor increase in the eastwards velocity on its eastern side evidencing also a minor extension of the structure. Episodic accelerations affect both faults and are visible on some interferograms from different sensors.
The dense GPS network is measured periodically and has more than seventy benchmarks. The time series of this network began in 1988 and from then on its configuration has been continuously improved. Two GPS networks lie across the eastern segment of the Pernicana fault. The first one, located in the Rocca Campana area, was installed in April 1997; the second one, located a few kilometers westward, in the Rocca Pignatello area, was measured for the first time in July 2002 upgrading an EDM network. The aim of these networks is to detail the structural framework and displacements along the aseismic sector of the Pernicana fault.
Integration of this wide spectrum of geodetic data allows strongly constrained ground deformation pattern to be defined and modeled. Furthermore, the very long time series available for the different datasets on the Pernicana fault, allows its behavior to be investigated in time and its role and relationships in the framework of flank instability and eruptive activity to better understood.

S5.2 - Presentazione orale

Dynamics of the 1989 fracture system and relations with the Etna eruptive activity of the last 30 years

INGV OE-OV Etna-Volcano Deformation Group*

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On September 11, 1989, after four months of Strombolian activity at the summit craters, effusive activity began on Mt. Etna and lasted about a month.
The 1989 eruption of Mt. Etna was characterized by the formation of two fracture systems, striking NE-SW and NNW-SSE, and both starting from the SE Crater on September, 24.
The NE-SW system was followed by effusive activity while the NNW-SSE fractures opened for a length of 7 km without eruptive phenomena. Between September, 27 and October, 3 the fracture system propagated until it reached and cut the SP 92 provincial road (Zafferana - Rifugio Sapienza), near the 1792 effusive mouth, and continued southward for another 700 m.
We investigated the fracture southern branch dynamics through 30 years of ground deformation data collected by the discrete and continuous INGV monitoring networks. We considered levelling, GPS, EDM, and extensometers data. EDM and levelling measurements began in the 80s; on 2003 EDM measurements have been replaced by GPS.
During the 1989 eruption, EDM measurements showed variations of tens of centimeters on the lines close to the fracture.
Precise levelling discrete measurements revealed, in the period 4-16 October 1989 and during the 1991-1993 eruption a subsidence of some centimeters on benchmarks close to fracture.
A network of rod extensometers evidenced the fracture activation during the 2001 intrusion phases (12-17 July) measuring several centimeters of left lateral slip. Distance measurements and InSAR show signs of the fracture reactivation during the 2002 and 2018 eruptions.
Several authors show as the 1989 fracture zone connects the summit region of the volcano with the tectonic structures of the lower SE flank considering it as well part of the NNW-SSE oriented structure.
The dynamics of these last 30 years suggests that the 1989 fracture play an important role on the flank dynamics and strain distribution. It also represents a potential hazard to population because it represents a possible way of ascending magma also testified by cones aligned along the structure.

S5.3 - Presentazione orale

Relationships between faulting and volcano-tectonic processes/events at Campi Flegrei caldera

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This work focuses on the characterization of deformation structures hosted in the post NYT (15 ka) sequence in both continental and marine areas of Campi Flegrei caldera. A structural survey has been carried out on the rocks exposed on-land. Measurements of fractures, faults, and sedimentary dikes have been collected and analyzed, as well as their relationships with the pyroclastic successions. In particular, we focused on the western and central sectors of the caldera, including the nowadays most active area of hydrothermal activity (Agnano-Solfatara). Results indicate the presence of four fracture and fault sets, consisting of older Appeninic/Anti-Appeninic and younger NNE-SSW/WSW-ENE trends. The former structures generally cut the volcanoclastic succession up to Agnano-Monte Spina (AMS) tephra (4.55 ka); the latter faults are hosted within Astroni tephra (4.2 ka). The submerged portion of the caldera has been investigated through multiscale seismic lines, which allowed us to map in detail the major fault systems. Two main fault systems have been identified according to location and attitudes. The first system is localized in the central part of the caldera, coinciding with the ~15 km^2 apical dome area. We recognized high angle faults (dip > 75°) oriented with similar trend compared to the continental ones. However, the NNE fault set can be divided into two sub-sets, with the occurrence of steeper normal faults in a 2.5 km^2 limited area. The observed trends are consistent with that measured on-land. The second fault system consists of the ring faults bounding the Campi Flegrei caldera, depicting an arcuate lineament from Nisida/Bagnoli (to the East) to Bacoli-Baia (to the West). This ring fault system is characterized by mean dips of 65° and main E-W and NNW-SSE directions. To retrieve the time frame of activity of these faults and their relationships with the major volcanic and sedimentary markers, the latter has been interpreted and correlated in the seismostratigraphic sections through a study of seismic facies with the well-constrained stratigraphy on-land.

S5.4 - Presentazione orale

Structure and present state of the Astroni volcano (Campi Flegrei, Italy) highlighted from multidisciplinary high-resolution investigations

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The Campi Flegrei caldera was very active during the period among 5.5 and 3.8 ka, with major vents opening within the central-eastern sector of the caldera. One of the best-preserved volcanic edifices is the tuff ring of Astroni, which formed after a complex eruptive history characterized by at least seven distinct eruptions. The volcanic and magmatic history of the Astroni volcano as well as the characteristics and distribution of the deposits have been reconstructed, while the structural setting and present state of the volcano is still very poorly known.
In this study, we present new multidisciplinary data aimed to acquire new insight about the structure in-depth and the volcanic activity of the Astroni volcano, obtained by new structural, geophysical and geochemical data. Another important aim of this research is to define in detail the relationships between volcano-tectonic structures, rock bodies, and fluid circulation, in a recent volcano where different volcanic conduits, small scoria cones, lava domes, and lakes are located, and where very recently hydrothermal emissions have been reported.
The structural volcano-tectonic study includes both field surveys and laboratory work. Exposed fractures and faults have been studied, as well as the study of orthophotos and DEMs of the study area, to realize a map of lineaments. Geophysical investigations have been carried out through an electrical resistivity tomography (ERT) of the shallower part of the Astroni crater, aiming to detect the main formations, fault, main discontinuities and fluid patterns laying in the first 100 m depth in correspondence of an about 1.5 x 1.5 km2 area covering the whole crater. The resistivity data, collected along 2D lines, have been jointly inverted adopting a commercial 3D code, ending in a pseudo-3D resistivity model of the area. Furthermore, mappings of the soil self-potential and temperature have been performed. The detected SP anomalies are related to the effects of the hydrothermal systems present in the Astroni volcanic environments.
Diffuse soil CO_2 flux has been measured within the Astroni crater, and samples of gas bubbling through the lake have been collected and analyzed for chemical and isotopic composition. Preliminary results indicate a CO_2 rich (~98%) gas composition with a minor amount of atmospheric components (Air Saturated Water) and methane (~0.1%). Carbon isotopic composition of CO_2, similar to the composition of the fluids released by the Solfatara fumaroles, suggest a hydrothermal origin for these fluids.
The analysis of the different anomaly patterns, evidenced by the concurrent mapping of faults and fractures, self-potential, surface temperature, soil CO_2 flux, coupled with the examination of the electrical tomograms and the geologic observations, has led to a funded structural

interpretation, which outlines the circulation of hydrothermal fluids below the Astroni crater through possible active volcano-tectonic structures. This, in turn, will help in developing a more appropriate scenario of volcanic hazard in case of reactivation in this sector of Campi Flegrei caldera.

Deep Electrical Resistivity Tomography of the northern sector of Ischia active volcano (Italy): an outline of subsurface structures and fluids circulation

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The island of Ischia is a well-known example of resurgent caldera, which underwent to about 900 m of uplift occurred intermittently during the past 50 ka. The volcanism of the island, as well as its resurgence, are both correlated with the dynamic of a shallow magma body. During historical and recent time, the northern sector of the island was hit by destructive earthquakes (e.g. 1769, 1828, 1881, 1883, 2017) which produced many fatalities and damages at Casamicciola Terme. This sector represents the northern rim of the resurgent structure (the Mt. Epomeo) which appears the part of the island affected by larger deformations and faulting, occurred during the uplift. A robust and high-temperature geothermal field was developed along the structural boundary of the Mt. Epomeo, producing an intense process of hydrothermal alteration of the crust, that is evident along the northern, western and southern sectors of the island. The island volcano-tectonic models, proposed in the literature, have investigated on the relationship between the tectonic evolution of the resurgent block, the hydrothermal circulation and the seismic activity. However, all such efforts suffer of the lack of a specific definition of the Ischia northern sector structures, which would be relevant to characterize the hydrothermal circulation, as well as the seismogenic structures. The results of a deep Electrical Resistivity Tomography, performed in this work, give original hints, obtaining a three-dimensional model of the electrical resistivity over an area of about 3x1.5 km^2, which extends down to a depth of 400 m, along the northern sector of the island. The interpretation of the electrical anomalies, integrated with the geological and geochemical evidences, allows to reconstruct the pattern of the shallower hydrothermal circulation, and the main shallow tectonic structures of the norther boundary of Mt. Epomeo.

S5.6 - Presentazione orale

Integrating petrologic with geophysical and geochemical data: a critical review to identify best practices for petrologic monitoring of ongoing eruptions

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The migration of magma toward the surface prior to an eruption and the evolution of the magmatic systems produce signals that can be measured by seismic, geodetic and gas monitoring arrays located around active volcanoes. The scarce knowledge of the processes controlling the transition between quiescence and eruption limits our ability to decipher monitoring signals of volcanic unrest, and thus to predict the onset and the characteristics of eruptions. The unequivocal interpretation of the pre- and syn-eruptive processes that generate real-time signals requires to know the rheological properties of magma (melt, crystals, and bubble), the depth and geometry of storage zone/s, the structural context of the volcano edifice, as well as their evolution over the time. Most of this crucial information can be obtained by the petrological monitoring of the erupted products (lava flows and pyroclasts), focusing on the study of their petrography, rock textures and chemical compositions.
The key point of the petrological monitoring of an ongoing eruption is to carry out the sampling of eruptive products as regular as possible and to perform rapid laboratory analyses, to address the variation of petrological parameters over time. For example, the analyses of tephra, which include grain size, particles morphology and clast componentry, give information on style and dynamic of magma fragmentation; textural features, which include mineral assemblage and vesicles population, as well as chemical analyses provide information about pre and syn-eruptive processes that led to magma ascent, such as the involvement of different magma batches or rejuvenation.
This work, which is carried out in the framework of EUROVOLC project activities, is focused to analyze data of a few case study eruptions, that are selected on the basis of the type of volcanic activity, availability of real-time monitoring signals and petrological data productions. This multidisciplinary approach would disclose the linkage between the rock record (petrology of erupted products) and the real-time (geophysical and geochemical) monitoring, in order to anticipate possible development of an eruption. The cases of study considered include eruptions of Etna (2001), Stromboli (2007-08), Piton de la Fournaise (2007), El Hierro (2011-12), Bardabunga-Holuhraun (2015) and St. Helens (1980). The selected cases of study cover a broad variety of volcanic activity, among which fissure-fed effusions and lava fountains, ash-rich explosions, submarine, caldera-collapse, and dome-forming eruptions, within different geodynamic context and with different magma compositions, spanning from basalt to trachydacite and rhyolite.
The final purpose of this work is to suggest the best practice to be used for petrological monitoring during volcanic crises. To this aim, it is crucial to assess what types of petrological parameters are suitable to reveal possible evolution of an ongoing eruption together with easiness and speediness of acquisition for effective real-time monitoring. Finally, this work should promote the development of protocols among volcanic observatory worldwide to better perform petrological monitoring, allowing their interaction on a solid and standardized routine.

Acquiring this knowledge will set the path for a deeper comprehension of volcanic eruptions onset and evolution and will improve the quality of interpretation, sustaining the actions of decision-makers both in terms of hazard mitigation before eruptions and of crisis management during eruptions.

S5.7 - Poster

Monitoring active fumaroles through electrical resistivity tomograms: an application to the Pisciarelli fumarolic field (Campi Flegrei, Italy)

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The unrest of the Campi Flegrei caldera (CFc) is characterized primarily by shallow hydrothermal manifestations, vigorous gas emissions and seismic activity. The recent literature on the interpretation of the unrest of the CFc points out the role played by processes involving the area of the Solfatara crater and the nearby Pisciarelli zone, which are the sites presenting the major activities during the last decade. In order to characterize the fumarole field of Pisciarelli, Electrical Resistivity Tomography (ERT) and Self Potential surveys have been recently realized, taking advantage of the capability of these two techniques to resolve shallow structures, evidencing at the same time the volumes permeated by hydrothermal fluids.
A first ERT prospection has been carried on in correspondence of a 100 m long survey line, which crosses along the W-E direction the Pisciarelli permanent mud pool and its main fumarole. The survey has been repeated bimonthly, adopting a time-lapse approach useful to evaluate the possible influence of seasonal effects on the hydrothermal system. The comparison with temperature, geochemical data and rainfall rates allowed to separate the areas dominated by seasonal effects from areas where deeper injected gasses cumulate in the subsoil. Three further ERT surveys has been performed in order to reconstruct the main Pisciarelli structural setting and the relationships between the main fractures and faults and the underground fluid circulation. A mapping of the self-potential anomaly for the whole Solfatara-Pisciarelli area has been also realized.
The results of the performed electrical investigations revealed the occurrence of zones characterized by intense and complex faulting and fracturing processes, affected by a strong fluid circulation, whose activity is also testified by the presence of fumaroles at the surface and strong hydrothermal alteration of the rocks.

S5.8 - Poster

Shallow magmatic crystallization processes at Piton de la Fournaise (La Rèunion Island, Indian Ocean) as inferred from subvolcanic mafic and ultramafic ejecta

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Réunion Island is a large and dominantly effusive basaltic volcanic oceanic system in the southernmost part of the Mascarene Basin (Indian Ocean), 800 km east of Madagascar, located at the youngest end of the hot spot track, which produced the Deccan Trapps. The island consists of two juxtaposed volcanic massifs, the oldest Piton des Neiges (in the north-west) and the youngest, presently active Piton de la Fournaise (PdF, in the south-east). A third, poorly known buried volcano, named Les Alizés was mainly defined through exploratory drilling and constitutes the basement of PdF.

The construction of PdF sensu stricto started at about 400/450 ka. Its lavas are mainly transitional basalts defining a differentiation trend towards mugearites, intermediate in character between the alkaline and tholeiitic series, both aphyric ("cotectic basalts") and olivine-rich ("oceanites"). They slightly differ from Les Alizés aphyric basalts ("abnormal group") that belong to the more alkalic (K_2O -rich) series, with higher MgO and lower CaO and SiO_2 contents. The moderate chemical heterogeneity has been since long attributed to a combination of slight mantle source heterogeneity and influence of clinopyroxene fractionation at mantle/underplating depth. Magmas stored in the crustal depth range and erupted by the summit area are quite homogeneous and result from the hybridization process of "tholeiitic" and "alkaline" end-members.

Large caldera forming events (e.g., "Bellecombe Ash Member", BAM, ≈5.5-3.0 ka; the largest explosive activity produced by PdF) involve, as ejecta, a large fraction of the crustal plumbing system and allow to i) access to a rare snapshot of the magmatic processes (cumulate vs. in situ crystallization; volatile exsolution and percolation; melt and rock assimilation) occurring below one of the most active basaltic volcanoes of the world, and ii) study the magmas driving these rare but very hazardous geological events.

The petrographic study of more than one hundred samples representative of the ejecta within the BAM emphasizes the presence of many subvolcanic mafic and ultramafic igneous rocks: dunites, wherlites, ophitic gabbros, sub-ophitic gabbros, pecilitic gabbros, dolerites and porfirogabbros. A wide range of textures in these ejecta results from variable P-T gradients in the subvolcanic environment of crystallization. Cumulate cognates sensu stricto are present, as also inferred from the abundant quenched basaltic glass entrapped interstitially and in minerals (melt inclusions), with no disequilibrium textures induced into the subvolcanic crystal frameworks. These clasts permit to target the transcrustal plumbing system still active during large caldera forming events, and to compare the compositions of the interstitial glass in the subvolcanic ejecta with small volumes of evolved liquids (latites/trachytes from petrographic observation) detected as pumiceous components in the products of the PdF caldera-forming eruptions.

Other subvolcanic clasts (e.g. dolerites) may simply represent slowly-cooled equivalents (with no crystal-liquid fractionation) of the erupted magmas.

Chemistry of both minerals (olivine, clinopyroxene, feldspar, oxides, biotite) and interstitial glass from the subvolcanic ejecta has been performed by Electron Micro Probe Analyzer (EMPA) whereas a fluid inclusion chemical and thermobarometric study (CO_2, H_2O and noble gases) is ongoing on selected olivine, clinopyroxene, and feldspar crystals. A comprehensive geochemical comparison among the analysed samples (ICP-OES-MS major-trace elements) and the whole compositional spectrum of the PdF and Les Alizés volcanic rocks available from literature has been also carried out. Sr-Nd isotope systematics on representative samples will be also performed.

Moreover, as the large explosive event of the BAM could have disrupted the subvolcanic plumbing system of both PdF and Les Alizés, the whole crystallization/fractionation trends of the studied mafic and ultramafic ejecta will be compared with those (i.e. “dunitic” to “wherlitic” and “gabbro”) of the main extrusive products of the La Réunion Island oceanic system (“cotectic basalts”, “oceanites” and “abnormal group”) inferred by the literature.

S5.9 - Poster

S6. MECHANISMS, RATES, AND TIMESCALES OF PROCESSES LEADING THE TRIGGERING AND EVOLUTION OF VOLCANIC ERUPTIONS

Conveners:
Marisa Giuffrida (UniCt), Silvia Massaro (INGV-BO),
Maurizio Petrelli (UniPg), Roberto Sulpizio (UniBa)

Causes of ciclicity in lava dome eruptions

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Modern geophysical data recorded during lava dome building eruptions show multiple dominant periodicities, ranging from short-term cycles, with time scales of hours, to long-term cycles, with time scales of years. Several models, which consider nonlinear dynamics of lava dome eruptions accounting for gas exsolution, bubble growth, decompression-induced crystallization, and effects of magma temperature variation, have been proposed to explain the observed cyclicity in the last decade. These nonlinear dynamic models show that each of these dominant cycles can be basically attributed to different regions of the volcano plumbing system.
Several studies indicate that short-term cyclicity (hours to weeks) is modulated by the coupling between the shallowest and deeper parts of the conduit, with the lower region acting like a capacitor, allowing magma to be stored temporarily in order to be released during the intense phase of the eruption. Regarding long-term cycles (months to years), the periodicity is controlled mainly by the volume of the elastic magma chamber and intensity of magma influx rate. However, in presence of a shallow and a deep reservoir periodicity is also controlled by the degree of connectivity of between the two reservoirs. For a weak connectivity the overpressure in the lower chamber stays nearly constant during the cycle and the influx of fresh magma into the shallow chamber is also nearly constant. For a strong connectivity between the chambers their overpressure increases or decreases during the cycle in a synchronous way.
Although real world systems are more complex and have many controlling parameters that may vary simultaneously, model results have important implications for the associated volcanic hazards assessments. A volcanic system may be quite predictable when it is within a stable regime, but may become inherently unpredictable when variations in the parameters move the system towards transition points and flow regime boundaries. This paper aims to review the state of the art of this topic and present perspectives for further improvements.

S6.1 - Presentazione orale

Cyclic activity and eruptive styles at Volcan de Colima (Mexico): insights for effusive-explosive transitions at calc-alkaline volcanoes

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Eruptive style transitions are frequently observed at many volcanoes around the world. In particular, eruptions involving the formation of lava domes can show recurrent transitions to Vulcanian explo- sive eruptions, and occasionally to sub-Plinian and even Plinian events. Examples include Unzen, Mount St. Helens, Santiaguito, Lascar, and Soufrie're Hills volcanoes. Changes in eruptive style imply variations in magma flow dynamics, which may mirror modifications in the driving pressure or conduit geometry. Changes in magma composition and rheology may also account for possible changes in eruptive behaviour. The Fuego de Colima volcano (Mexico) exhibited quasi- equilibrium conditions (at least) in the last five centuries, developing a summit dome that is occasionally dismantled by Vulcanian and (rarely) sub-Plinian explosive eruptions. The 1913 eruption was the last sub-Plinian event at Fuego de Colima and provides a well- documented example of the eruptive style transition from dome extrusion to a sub-Plinian explosive event. We present here a Morlet analysis of eruption rates that unravels different time lengths of cyclicity and a first-order discussion of the physical processes that drove the transition of the 1913 eruption from a slow dome extrusion into an explosive eruption by means of numerical simulations carried out with the CPIUD code, experimental petrology and data from finite element modelling, which provided assessment of the effect of gravitational loading on the volcano spreading.

S6.2 - Presentazione orale

Temporal evolution of effusion rate during basaltic eruptions: insights from numerical modelling

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Effusion rate is the most relevant factor controlling the dynamics and evolution of effusive eruptions, determining the emplacement conditions, length and morphology of lava flows. Accordingly, during the last decades, several efforts have been performed for the classification and interpretation of effusion rate curves. Here we show the results associated with the systematic application of a recently published numerical conduit model for studying the influence of magma source and feeding dike properties on the main features of the resulting effusion rate curves (e.g., duration, erupted mass, maximum and mean effusion rate). We show that the total erupted mass is mainly controlled by magma reservoir conditions prior to the eruption (i.e., magma reservoir size and initial overpressure), whereas conduit processes such as erosion by fluid shear stress along with reservoir properties can significantly affect the mean effusion rate, and thus they dramatically influence the eruption duration. Simulations reproduce a wide variety of effusion rate trends. These curves were classified in four groups using appropriate characterization and clustering techniques, which were associated with the different types of effusion rate curves described in the literature. Results agree with the traditional explanation of effusion rate curves and provide new insights for interpreting them, stressing the importance of magma reservoir dimensions, initial overpressure, and initial width of the feeding dike in controlling the effusion rate curve.

S6.3 - Presentazione orale

Non-explosive magma fragmentation during the 1888-90 eruption of Vulcano (Aeolian Islands): insights from breccia-bearing blocks

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Vulcanian activity is characterized by the repeated occurrence of explosions which release large amounts of gas and ash and ballistically eject coarse bombs and blocks. During this activity, the frequency of explosions can largely vary with intervals ranging from minutes to weeks. These explosions are generally interpreted as related to the partial to total destruction of domes or plug/conduit structures due to degassing and local magmatic gas accumulation. The 1888-90 eruption of Vulcano Island (Italy) represents the prototype of Vulcanian eruptions and was masterfully described in large details by scientists like Mercalli and De Fiore.
In their chronicles, activity was primarily classified according to a scale of intensity of the different explosions, which were frequently clustered in phases with similar characteristics. Phases dominated by low-intensity explosions in some cases were characterized by a very high frequency of occurrence, reaching up to hundreds of events/day, so posing interesting questions about the possible mechanisms of magma fragmentation.
The present crater area is covered by the products of the 1888-90 eruption which include an extensive bomb field of different types, from the classical breadcrust bombs to very dense blocks. Bomb and block types are representative of the different zones of the conduit/plug system involved in the explosion and suggest the existence of large vertical and lateral gradients in the magma column immediately prior the eruption. Among the different types of ballistic fragments, breccia-bearing, dense blocks are scattered over the whole crateric area. These dense blocks are characterized by the presence of fractures filled with pyroclastic material.
A detailed study of grain-size, clast morphology and arrangement, lithological and textural features of the clast was performed on the fracture-infilling material of different blocks. The finer-grained material present in the fracture was then compared with the morpho-textural characteristics of ash emitted during the phases of more intense activity, collected from two stratigraphic sequences at different distances from La Fossa cone.
Pyroclastics infilling of the fractures is interpreted as the product of mechanical, shear-related fracturing of the rigid, hot upper portion of the conduit. Ash transport within the fracture network is suggested by the co-presence of material derived from the shattering of different portions of the plug. Gas-driven elutriation of ash material present in the fracture network could have been responsible for the ash emission activity which characterized the lower intensity phases of the eruption, that were not able to produce an efficient primary fragmentation of the magma.

S6.4 - Presentazione orale

Highly explosive basaltic eruptions: magma fragmentation induced by rapid crystallisation

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Basaltic eruptions are the most common form of volcanism on Earth and planetary bodies. The low viscosity of basaltic magmas generally favours effusive and mildly explosive volcanic activity. Highly explosive basaltic eruptions occur less frequently and their eruption mechanism still remains subject to debate [Szramek, 2016; Moitra et al., 2018], with implications for the significant hazard associated with explosive basaltic volcanism. Particularly, highly explosive eruptions require magma fragmentation, yet it is unclear how basaltic magmas can reach the fragmentation threshold [Papale, 1999; Gonnermann, 2015].
In volcanic conduits, the crystallisation kinetics of an ascending magma are driven by degassing and cooling [Cashman and Blundy, 2000; La Spina et al., 2016]. So far, the crystallisation kinetics of magmas have been estimated through ex situ crystallization experiments. However, this experimental approach induces underestimation of crystallization kinetics in silicate melts. The crystallization experiments reported in this study were performed in situ at Diamond Light Source (experiment EE12392 at the I12 beamline), Harwell, UK, using basalt from the 2001 Etna eruption as the starting material. We combined a bespoke high-temperature environmental cell with fast synchrotron X-ray microtomography to image the evolution of crystallization in real time. After 4 hours at sub-liquidus conditions (1170 °C and 1150 °C) the system was perturbed through a rapid cooling (0.4 °C/s), inducing a sudden increase of undercooling. Our study reports the first in situ observation of exceptionally rapid plagioclase and clinopyroxene crystallisation in trachybasaltic magmas. We combine these constraints on crystallisation kinetics and viscosity evolution with a numerical conduit model to show that exceptionally rapid syn-eruptive crystallisation is the fundamental process required to trigger basaltic magma fragmentation under high strain rates. Our in situ experimental and natural observations combined with a numerical conduit model allow us to conclude that pre-eruptive temperatures <1100°C favour the formation of highly explosive basaltic eruptions, such as Plinian volcanism, driven by fast syn-eruptive crystal growth under a high undercooling and high decompression rates [Arzilli et al., 2019]. This implies that all the basaltic systems on Earth have the potential to produce powerful explosive eruptions.

S6.5 - Presentazione orale

Fixing magma ascent velocity through volatile diffusion in olivine melt tubes

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The explosivity of an eruption is determined by many factors, including magma viscosity, crystallinity, gas content, size of the conduit and magma ascent rate. In this regard, the role of magma ascent rate is prominent especially in violent eruptive episodes occurring when only basic magma is involved or at open conduit volcanic systems, where low viscosity, basic magmas generally feed weak explosive and/or effusive activity. A recent approach of investigation based on diffusion chronometry of volatile species along olivine-hosted embayments has been used to fix ascent rates for some eruptions occurred in arc volcanoes. This approach measures compositional gradients of volatile elements that are produced by diffusion from the inner part of the embayment toward the outer melt as a response of degassing-induced decompression. Numerical modeling can retrieve timescales of diffusion, allowing an estimation of ascent rates. In addition, possible changes of ascent rates over a range of depth can be estimated by modeling of multiple volatile species (i.e. H_2O, CO_2, S) with different solubility and diffusivities. Quantification of volatile species dissolved in olivine-hosted melt inclusions is necessary for recognizing the original volatile contents in the magma, in order to track the degassing path and to determine the exsolution depth for each volatile component. Thus, initial volatile contents and initial pressure before decompression, which are useful for the application of the numerical model, can be constrained through melt inclusion-based studies.

We have chosen Mt. Etna volcano as case of study, which is one of the most active open conduit volcanoes worldwide. Although its ordinary activity is Strombolian with effusion of lava flows, some violent manifestations occurred both in historical and recent times, where basic and ultrabasic magmas have been involved. We selected three eruptive episodes characterized by different explosive intensity from the post-2011 recent activity at Mt. Etna, in order to figure out a range of ascent rates related to the different explosive intensities. The recent eruptive episodes include: 1) the paroxysmal episode of the February 19, 2013 at the New South East Crater (NSEC); 2) the violent eruption of the December 3, 2015 occurred at the Voragine Crater; 3) the flank eruption that affected the southeastern sector of the volcanic edifice on December 24, 2018. In this study, we present preliminary results on the olivine-hosted melt inclusions and embayments found in tephra erupted during the above-mentioned selected eruptions. Micro-Raman spectroscopy has been used for quantification of the water contents, whereas major elements, S and Cl contents in melt inclusions have been determined through electron microprobe. Water contents in melt inclusions range between 0.3 and 2.2 wt.%. Major element compositions put into evidence the existence of at least two types of melt inclusions. The first type of melt inclusions is characterized by K_2O ca. 2.4-2.9 wt.%, CaO ca. 6.0-9.2 wt.%, Mg# 48-54 and S ca. 275-1245 ppm; these have been found entrapped in olivine crystals with Fo_{76-79}. The second type of melt inclusions shows K_2O content of ca. 1.7-2.1 wt.%, CaO ca. 9.8-12.3, Mg# 55-61 and S ca. 1500-2900 ppm; these have been found in more primitive olivine crystals with Fo_{80-84}. H_2O measurements along olivine-hosted melt embayments display averages value of 1.3-1.7 wt.% in the inner part of the olivine embayments for the February 19, 2013 and

December 3, 2015 products whereas, the December 24, 2018 products exhibit more water-depleted concentrations, with average values at 0.3-0.5 wt.%. At present, we are finalizing the CO_2 collection in melt inclusions in order to better constrain the degassing path for each eruptive episode. Integration of the whole dataset obtained on olivine-hosted melt inclusions and olivine melt tubes will furnish important indications on potential differences in the decompression-driven timescales of degassing for magmas emitted with markedly distinct eruptive dynamics at Mt. Etna volcano.

S6.6 - Presentazione orale

Degassing of evolved alkaline melts: the effect of decompression rate and volatile (H_2O-CO_2) content

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Volatile exsolution during magma decompression in volcanic conduit induces bubbles "birth, life and death", thus providing the driving force for eruptions and controlling magma ascent as well as eruptive style. In the last decades many studies have been focused on rhyolitic melts allowing the definition of a well-recognized paradigm of their degassing. Recently some investigations on evolved alkaline magmas have been carried out, however numerous open questions still remain on how their degassing works. These magmas frequently feed many active high-explosive volcanoes (e.g. Campi Flegrei caldera, Somma-Vesuvius, Azores islands), despite their low viscosity. Therefore, expanding the knowledge on kinetics and dynamics of their degassing can be crucial for volcanic hazard assessment.
In this study we investigated the homogeneous bubble nucleation and degassing behavior of trachytic melts through high temperature - high pressure experiments and numerical modeling of magma vesiculation. Particularly, we performed isothermal decompression experiments at super-liquidus temperature (1200Â°C) changing final pressure (from 200 to 25 MPa, with intermediate steps every 50 MPa), decompression rate (0.01 and 1 MPa/s) and glass volatile content (XH_2O=1, XH_2O=XCO_2=0.5, XCO_2=1 saturated fluids and water-oversaturated fluids at 200 MPa). Experimental samples were 3D texturally (i.e. bubble and Fe-Ti oxide parameters) and chemically (i.e. glass volatile content and nanolite investigation) characterized. 3D microtextural examination was carried out using X-ray computed microtomography, a powerful tool for the 3D quantitative analysis of large sample volume at high resolution, not directly provided by 2D conventional techniques.
Our results suggest that homogeneous bubble nucleation in evolved alkaline melts is mainly controlled by initial volatile content and can occur with lower supersaturation pressures and higher bubble number density than in rhyolitic magmas, especially at slow decompression rates, possible enhancing magma buoyancy and eruption explosivity. Moreover, faster decompression and presence of CO_2 lead to closed-system degassing regime, whereas slower decompression and H_2O-dominated degassing promote the development of magma permeability and inertial fragmentation.

S6.7 - Presentazione orale

Experimental simulation of ascent and fragmentation of Stromboli LP magmas

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Both high temperature and pressure isobaric and decompression experiments were performed on Stromboli LP magmas to shed light on magma ascent velocities (u) and on paroxysm incubation mechanisms and timescales. The decompression experiments mimic the ascent of LP magmas from their source region up to their intrusion in the HP magma. Either constant u (from 0.25 to 3 m/s) or variable (> 1 and < 1 m/s above and below 50 MPa respectively) were imposed. All experiments started from a natural yellow pumice and three different melt H_2O concentrations (~5, ~2.5, ~1 wt%) were investigated, CO_2 being present (800-1100 ppm) in the two less H_2O-rich melt series. Most decompression experiments yielded crystal-free glasses except the longest (8.3 h) at 1150°C which crystallized olivine and clinopyroxene. Thus, LP magmas must travel from their source region in < ~10 h corresponding to u > ~0.25 m/s (if assumed constant during ascent). Bubble number densities (BNDs) show the expected increase with increasing u and BNDs in yellow pumices are bracketed by 1.5 and 3 m/s ~2.5 melt series charges. In those, average bubble diameters (D) are lower than in yellow pumices but increase markedly with decreasing u. Natural bubble D are bracketed by 0.64 and 1 m/s ~2.5 melt series charges suggesting that u could decrease at shallow levels < 50 MPa. Most petrological estimates converge toward an average u of ~1 m/s for LP magmas, higher by >1 order of magnitude than geophysical estimates. LP magmas resided at shallow levels for no more than a few h before being erupted as estimated from widths of plagioclase reaction zones experimentally calibrated as a function of time. Paroxysm incubation mechanisms include bubble growth and coalescence, bubble rise by buoyancy, generation of a new population of small bubbles and fragmentation. Fragmentation textures range from fluidal to brittle depending on the melt H_2O content. Paroxysm incubation involves generation and overpressurization of a gas-rich suspension and should closely follow (~1h) the arrival of a LP magma batch at shallow levels.

S6.8 - Presentazione orale

A multidisciplinary investigation of the December 24-26, 2018 fissure eruption at Mt. Etna volcano

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Since the violent paroxysmal eruptions of May 2016, volcanic activity at Mt. Etna exhibited a transition in eruptive frequency and magnitude, generating almost entirely effusive eruptions from both summit craters and the volcano flanks. The most recent flank eruption occurred on December 24 2018, about 10 years after the last flank eruption of 2008-09. This episode followed the opening of eruptive fissures at the base of the New South-East Crater (NSEC) cone, which rapidly propagated southeastward and were accompanied by resumption of low-intensity explosions at the summit vents between December 24-26. The Strombolian activity along the fissures fed lava flows spreading across the Valle del Bove, though - notably - only about 1 million of m^3 of lava was erupted during the effusive phase.
To detect dynamics of magma supply preceding the December 24-26 2018 eruption, we propose a multidisciplinary approach of investigation in which petrological and geophysical observations have been combined. Crystal chemical zoning and diffusion chronometry data were elaborated and integrated together with GPS measurements collected from the permanent monitoring network of Mt. Etna during the two years preceding the eruption. Olivine crystals were selected and grouped in populations based on their core compositions and zoning types in order to detect the presence of magmas with distinct differentiation degrees. Olivine cores spanning from more basic (Fo84) to slightly evolved compositions (Fo_{70}) reflect crystal residence and growth in five magmatic environments, which are variably distributed beneath Mt. Etna. The physical parameters, such as P, T and $ƒO_2$, associated to each environment were constrained through thermodynamic modeling. For what concerns the pressure, high-Fo core compositions at Fo84 indicate a deep environment of crystallization at ca. 650 MPa, here indicated as M00; olivines with Fo80-81 cores are representative of the M0 environment located at pressure of 420-380 MPa; Fo78 cores refer to the M1a environment at 290-230 MPa; olivines with Fo76 core compositions belong to the M1b environment at 160-120 MPa, whereas the Fo70-74 cores cover a compositional range which is between 30 and 40 MPa (i.e., the environment M2). A detailed investigation of the diversity of the crystal chemical zoning from core to rim allowed the identification of some dominant paths of ascent and mechanisms of interaction between different magmas. This has led us to detect those environments that were reactivated before the eruption. Our petrological data support the reactivation of the deepest magmatic environments, located at pressure higher than 400 MPa. This is in accordance with the evidence for a deep magmatic source of inflation at ca. 7 km b.s.l., which has been inferred through geodetic data inversions. The inflation of the volcano edifice was detected since April 1, 2017 and continued at constant rate until the eruption onset on December 24, 2018, hence supporting a 20 months-long period of continuous replenishment into the feeding system. When compared with petrological and geodetic observations related to the past volcanic activity, our data support a plumbing system configuration that currently enhances episodes of deep replenishment and long-lasting storage at high depth, rather than shallow pressurization with frequent emissions of magma at the surface.

S6.9 - Poster

Conduit dynamics in the 1st February 2014 eruption of Tungurahua (Ecuador): inferences from volcanic bombs

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Mid-intensity explosive events frequently occur worldwide at volcanoes with intermediate to silicic magmas. Textural and compositional features of the different types of pyroclastic fragments (from ash to bomb-sized) demonstrated to be very useful to get insights into the conduit processes that strongly control the dynamics of these eruptions. We present here data on a vulcanian to subplinian event occurred at Tungurahua volcano (Ecuador) on 1 February 2014, when three large explosions occurred at intervals of few minutes. These generated short-lived sustained plumes between 4 and 8 km above the vent. The last eruption was the largest one and culminated with the formation of pyroclastic density currents (PDC) that reached the base of the edifice, at about 8 km of distance from the vent. Four different types of block and bombs were found in the deposits of these PDC: dense fragments (D), breadcrust bombs (BCB), cauliflower bombs (CFB) and foliated, banded bombs (FB). The ejected bombs represent samples of different parts of the magma in the conduit and preserve information that can be used to infer parameters of pre-eruption magma ascent. Samples were analysed for their morphology, density, groundmass texture and composition.
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 D, suggesting contrasting crystallization processes occurring within the conduit. These differences in groundmass glass composition are also accompanied by important variations in the textural characteristics of each type of bomb, thus suggesting the importance of pre- and syn-eruptive degassing-induced crystallization.
Coupling all these observations, we infer an explosive dynamics 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.

S6.10 - Poster

Evidence for magma migration leading to the 2014-2015 fissure eruption at Holuhraun (Northern Rift Zone, Iceland)

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The most common type of basaltic volcanism along the Icelandic rift zones are eruptions developing from fissure swarms connected in some way to main basaltic magma reservoir/s beneath central volcanic edifices. In this framework, the 2014-2015 fissure eruption at Holuhraun, within the Bárðarbunga volcanic system (Northern Rift Zone of Iceland), was one of the largest and most exceptional examples. The main phase of the Holuhraun eruption lasted from August 31, 2014 to February 27, 2015, emitting 1.6Â±0.3 km^3 of lava spreading across more than 84 square km, thus making the Iceland's largest lava flow field since the Laki eruption in 1783-1784. The eruption followed a dyke intrusion that originated at the nearby Bárðarbunga central volcano and propagated northeastward over ca. 48 km. The entire event was geophysically monitored in real-time since the first signals of volcanic unrest. Indeed, the migration of seismic swarms and associated ground deformations well tracked the lateral transport history of magmas along the DyngjuhÃ¡ls fissure swarm before the eruption. In conjunction with the evidence for lateral migration, some petrological constraints support a model of initial vertical magma ascent within the Bárðarbunga plumbing system followed by lateral movements toward the eruption site. At present, existing studies on the deep magma dynamics at Holuhraun still question if the eruption was fed from a multi-level magma storage region, instead of a narrow, mid-crustal depth interval.

In this study, we use the compositional and temporal record of olivine crystals erupted during the first eruptive stage to provide a thorough space-time reconstruction of the magma storage and transport history preceding this six-months-lasting fissural eruption. Coexisting olivines preserve records of a multilevel plumbing system through their Fe-Mg zoning. Cores cluster in a narrow compositional range between Fo78-82 indicating a common deep-seated magmatic reservoir in which crystals initially nucleated and grew. We recognized compositionally-distinct Fo plateaus in core-to-rim intermediate portions of olivine crystals and used them to track the residence and passage of crystals through different storage zones. Based on our observations, olivine crystals experienced up to two storage events between nucleation and eruption. A more detailed pre-eruptive picture of magma dynamics is finally obtained when the olivine chemical zonation is evaluated considering its time-dependent diffusive relaxation. Here, we aim to reconcile the olivine archive with existing seismic and geodetic determinations in order to track the transport history of magmas through the plumbing system and to track finally the lateral transport to the Holuhraun eruption site. When combined with monitoring data available, our petrological constraints on mechanisms of melt storage and transport mark a significant step forward to a reliable characterization of the volcanic eruptive behavior and the related hazard assessment.

S6.11 - Poster

Fluorine as a destroyer of silicate melt structures: evidence from the 1477 AD Laugarhaun rhyolitic lava flow (Landmannalaugar, southern Iceland)

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Viscosity of volcanic products chiefly depends on compositional factors of the magma. The silica content is the most prominent among these influencing factors, being silicon the most abundant element acting as network former in common natural magmas. Rheological behavior of basic magmas (i.e., SiO_2 45-52%) with viscosities around 10-102 Pa s is therefore markedly different if compared with that of more evolved magmas (e.g., rhyolites with SiO_2 73-77% and viscosities of 105-108 Pa s). Other elements, however, can have dramatic effects on the degree of polymerization of silicate magmas and on their final modes of emplacement, even when they are in minor concentrations. Among volatile elements, and halogens in particular, fluorine produces strong depolymerization through the substitution of F for oxygen via the exchange operator F2O-1, with effects becoming increasingly more pronounced for highly polymerized melts. Although the important role of fluorine has been so far recognized especially for the petrogenesis of basic magmas, dramatic rheological consequences also affect more evolved magmas. Indeed, fluorine is the most soluble elements among volatiles, which means it has the opportunity to be exsolved only in part during magma ascent and remains concentrated into the residual melt with significant amounts even during syn-eruptive conditions.

In this study, we have taken into consideration the Laugahraun lava flow (Landmannalaugar, southern Iceland), which was erupted around 1477 AD from the Brennisteinsalda in the area of the Torfajökull volcanic center. Torfajökull is located at the intersection between the Eastern Volcanic Zone (EVZ) and the South Iceland Seismic Zone (SISZ), and is characterized by one of the most impressive calderas (i.e., diameter of 18 km) among the Icelandic volcanoes. Although the obsidianaceous Laugahraun lava flow has rhyolitic composition, it has an odd aspect ratio if compared to other rhyolitic flows worldwide being characterized by mega-ropy lava structures that suggest peculiar rheological behavior during the emplacement. Ten samples from various portions of the lava flow have been therefore collected during the field survey conducted on July 2017, and they were investigated through XRF and mass spectrometry for what concerns the major and trace element abundances in order to verify the potential compositional effects on the viscosity. In this regard, chlorine and fluorine concentrations have been also determined on the same samples, which were collected respectively through standard XRF and Ion Selective Electrode coupled with potassium hydroxide fusion. Both major and trace element concentrations are clustered within a narrow compositional range (among LILE, Ba ca. 500 ppm; among HFSE, Zr ca. 650 ppm; among LREE, La ca. 80 ppm, Ce ca. 170 ppm; among MREE, Sm ca. 12 ppm, Eu ca. 2.5 ppm; among HREE, Yb ca. 6 ppm, Lu ca. 1 ppm). Fluorine concentrations span in the range 2000-2500 ppm, values about five times more than common values observed in rhyolitic products. Our data suggest that the rheological behavior of the rhyolitic lava flow of Laugarhaun in Landmannalaugar could have been influenced by the high content of fluorine stored into the melt structure. Importance of our findings consists in the determination of how compositional factors can dramatically affect the behavior of lava emplacement in specific settings developing uncommon flow dynamics.

S6.12 - Poster

New insights into pre-eruptive dynamics of caldera-forming eruptions: the case study of the welded scoriae of Vulcano (Aeolian Islands, Italy)

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The generation of calderas, generally related to syn- and post-eruptive phases of collapse of the roof of magma chamber, is often accompanied by highly-energetic eruptive events, potentially hazardous in terms of civil protection. Within the last 50 ky of volcanic activity, the morphology of the island of Vulcano has been interested by the formation of two main caldera depressions named "Il Piano" and "La Fossa", formed by several semi-circular segments of border faults. However, a certain ambiguity still remains about the identification of the related volcanic deposits, their stratigraphic position and their eruptive dynamics. In addition, the understanding of mechanisms of caldera collapse is notoriously difficult because proximal caldera-forming deposits are often obscured by later volcanic and tectonic activity.

Between 48 and 8 ka, volcanic activity at Vulcano has been characterized by the recurrent emplacement of massive reddish and poorly-to-strongly welded shoshonitic scoriae, mainly erupted from fractures located along the present borders of the Caldera of "Il Piano" (i.e., Monte Luccia, Spiaggia Lunga, Quadrara stratigraphic units) and of "La Fossa" (Saraceno unit). With the exception of Saraceno unit, the deposits of these eruptions show a pomiceous fall layer at their base, followed by cross-laminated tuff layers linked to the emplacement of dilute pyroclastic density currents. The most voluminous deposits belong to the Spiaggia Lunga eruptive unit, occurred ca. 24 ky along a fracture located in the western part of the island. This eruption produced a 50-m-thick sequence of deposits interpreted in literature as "lava-like" welded basaltic ignimbrites or, alternatively, welded scoriae produced by lava-fountaining activity and forming a density-stratified scoria flow.

The present study is focused on the pre- and syn-eruptive processes which acted during these welded scoriae-forming eruptions, in order to evaluate if they can be related to the emptying of a magma reservoir producing caldera collapses. The study has been carried out by means of textural and compositional (EMPA) studies of plagioclase crystals found within the scoriae, and of their whole rock compositions. Textural analysis on plagioclases highlighted 5 different types of crystal textures, namely: 1) oscillatory zoning; 2) strongly resorbed cores; 3) coarsely-sieved crystals; 4) resorbed envelops and 5) melt inclusion layers. The volcanological and petrologic significance of each texture has been determined through compositional profile core-to-rim on plagioclases. So, we defined the abundance of each texture in more than 2000 crystals (length > 500 μm), in order to relate their frequency (and then their related magmatic process) to the stratigraphic position of each sample within the deposit of each eruption.

Results of this analysis allowed to draw the pre-eruptive dynamics leading to the formation of the welded scoriae, and of the related eruptive scenario of caldera-forming processes. The trigger of each eruption would be related to a "criptic" mixing between a residing shoshonitic magma and a slightly more basic, but hotter and richer in volatiles, melt entering the magma reservoir. This is also showed by whole-rock compositions, which suggest that magma rejuvenation processes progressively acted during the whole duration of the eruption. For what concern the Spiaggia Lunga deposits, whose stratigraphic column is the best preserved, plagioclases registered a major event of decompression on the magma plumbing system during the intermediate phases of the eruption. We relate this event to the collapse of a portion of the Caldera of "Il Piano", as also suggested by the occurrence of a brecciated epiclastic deposit interbedded within the scoriae deposits. These data also agree with literature numerical simulations, which predicts rapid increases in magma decompression and mass discharge rates at the onset of caldera collapses. After this major event, up to seven minor events of collapse have been registered by plagioclase crystals, finally leading to the south-western-most volcano-tectonic collapse of "Il Piano" caldera. Future studies will be devoted to the determination of timescales of these magmatic processes in order to achieve a complete eruptive scenario of these highly energetic, and potentially hazardous, eruptions.

S6.13 - Poster

Olivines record variable dynamics of magma supply during the volcanic evolution of the island of Pantelleria

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The large variety of volcanic rock compositions and deposits at Pantelleria make the island an intriguing case study for researchers approaching to the study of volcanism in continental rift setting. A number of investigations and chemical analyses were carried out on felsic rocks and ignimbrite deposits associated to large scale explosive eruptions, whereas little is still known about the storage and transfer conditions of mafic magmas and how their evolutionary paths changed over time. Here, we investigate a comprehensive suite of basaltic rocks emplaced before and after the Green Tuff (GT) eruption (ca. 45 ka), discussing the observed geochemical signatures together with the chemical record preserved in volcanic minerals. In order to detect major changes in the plumbing system dynamics over time, basaltic rocks outcropping at different sites on the island were sampled and inspected for whole rock major and trace element compositions and the micro-chemical variations of minerals. The reconstruction of the storage and transport history of basaltic magmas follows the analysis of Fo zoning in olivine crystals, which has proved to be a valuable tracer of the changes in composition and physical characteristics of the host melt. We used compositional profiles across zoned olivines to document protracted periods of storage at magmatic temperatures, as well as interaction and mixing processes of differently-evolved magma batches. This information, together with the awareness of the rates of Fe-Mg diffusion in olivine has led us to extract the timing of magmatic processes, enabling us to clarify the dynamics that basaltic melts experienced before being erupted during the ancient > 45 ka) and most recent (<45 ka) eruptive period divided by the emplacement of the GT ignimbrite.
Results provide good indications of how the GT ignimbrite represented a turning point for the internal dynamics of the plumbing system. A large number of Fo87-88 olivine crystals support the dominant role of a primitive, high magnesian melt during the older (> 45 ka) volcanic history of the island. Over this period, olivine profiles document preferential routes of magma transfer from a deep storage zone close to the crust-mantle boundary towards the shallow section of the plumbing system at pressure between 315 and 215 MPa, with little or no evidence of residence at intermediate crustal levels (between 510 and 390 MPa). Estimated transfer timescales (> 2 years) are much longer than those recorded by the post-GT crystals (1-8 months), which contrariwise highlight magma dynamics involving more evolved and shallower (< 500 MPa) crustal reservoirs. The sequence and timescales of magmatic events recorded by olivine crystals indicate that the supply of the mafic magma greatly decreased after the GT eruption, albeit magmas encountered more favorable conditions for migrating throughout the upper section of the plumbing system.

S6.14 - Poster

Preliminary data results on the pre-eruptive mechanisms and trigger of the Perciato eruptive sequence at Salina (Aeolian Islands, Italy)

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The island of Salina, located in the central portion of the Aeolian archipelago, is the final result of the super-impositions of several eruptive centers along a 230 ky timespan. Each of them has a peculiar geochemical and petrographic signature and, consequently, specific eruptive dynamics and depositional mechanisms. One of the most intriguing features of the island is the presence of two volcanic edifices, Fossa delle Felci and Porri volcanoes, having similar size, height and morphology: the similarity led the ancient Greek people to name the island “Dydyme”, i.e. the “Twin mountains”. These two volcanoes also experienced periods of contemporaneous activity with different geochemical compositions of the emitted products.
The last phases of activity of Porri volcano has been characterized by Strombolian activity at its top, and by the emission of some lava flows which always reached the sea and are up to 50-m-thick in some flat areas. After a period of ca. 15 ky of rest, volcanic activity started again on the lower western flank of the Porri volcano. During this period, three major eruptive events occurred, namely: I) Perciato and Faraglione (ca. 30 ky ago), II) Lower Pollara (ca. 27 ky ago) and Upper Pollara (ca. 15 ky ago).
The present study focuses on the deposits of the Perciato eruptive unit, whose products form a ca. 50-m-thick sequence cropping out in the homonymous Punta di Perciato at Pollara and in the near Faraglione rock. The base of the volcanic sequence at Punta Perciato directly overlies one of the last lava flows of Porri volcano, and it is formed by a ca. 10-m-thick alternation of poorly welded and unsorted Strombolian scoriae and thin lava flows, often brecciated. In its intermediate portions a pink-to-red altered tuffaceous layer crops out. The Perciato sequence continues with a 20-m-thick lava flow, forming a spectacular rock arch at Punta di Perciato. This lava flow is surrounded by roof and top brecciated scoriae, and directly underlies the products of Lower Pollara. On the products of this volcanic sequence whole rock (XRF) analysis have been performed, together with textural and analytical (EMPA) investigations.
Textural analysis and core-to-rim compositional profile on plagioclases highlighted 5 different types of crystal textures, namely: 1) oscillatory zoning; 2) strongly resorbed cores; 3) coarsely-sieved crystals; 4) resorbed envelops and 5) melt inclusion layers. Plagioclase crystals with oscillatory zoning, and flat compositional profiles in terms of An and FeO, have been related to quiet crystallization processes in a basic magma reservoir located at intermediate crustal levels (< 11 km). Strongly resorbed cores and coarsely-sieved crystals are related to different ascent rates in water-undersaturated levels of the magmatic plumbing system. Resorbed envelops, which are characterized by an increase of the An content at relatively constant FeO, have been explained with the crystallization of a more anorthitic portion of plagioclase due to the ingress of a new magma with a similar whole composition of the resident one, but hotter and volatiles-richer (i.e., cripting mixing, an event of magma recharge in a closed-conduit system). Finally, melt inclusion layers are classically related to rapid decompression, with a consequent fast growth of the crystals, which incorporate magma droplets.
Once that the significance of each texture has been determined, we have defined the abundance

of each texture in more than 5000 crystals (length > 500 μm), in order to relate their frequency to their stratigraphic position. The two dominant plagioclase textures are oscillatory zoning and the melt inclusions layers. In particular, the abundance of plagioclase with melt inclusion layers increases from 25% at the base up to 45% in the intermediate portions of the stratigraphic sequence and suddenly decreases to 2-11% in the Perciato lava flow. Albeit oscillatory zoned plagioclase crystals in the lower and intermediate sequence reach values of 37-63%, they become dominant (75-87%) in the Perciato lava flow. Although more analyses are necessary, a possible (and preliminary) scenario which might explain the Perciato stratigraphic unit involves the onset of a new eruptive center, lateral with respect to the Porri volcano, and preceding the Lower Pollara eruption. The ascent of a basaltic magma, with a different geochemical signature in respect to the Porri's magma, was triggered by a sudden drop of lithostatic pressure, probably due to the flank collapse of the western sector of the Porri volcano. During the late stage of the eruptive event, or after a brief period of quiescence, a smaller pressure drop would have also triggered the ascent of the more evolved magmas of the Perciato and Faraglione lava flows, which were quietly residing and crystallizing at mildly crustal levels. Further analysis will be devoted to the recognition of all the pre-eruptive mechanisms and of their timescales.

S6.15 - Poster

Spatial Reconstrunction and Temporal Activation of the Magma Storage Zones Beneath the Eastern Volcanic Zone, Southern Iceland

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Iceland is the subaerial expression of the Mid-Atlantic Ridge (MAR), along which the Eurasian and North American plates are moving apart at about 20 mm per year. Here, the spreading plate boundary volcanism is complicated by the interaction with an inferred mantle plume. The major volcanic lineaments in Iceland are represented by an axial zone, which is delineated by the Reykjanes (RVZ), the Western (WVZ), the Northern (NVZ) and the Eastern Volcanic Zone (EVZ), running westward from the east coast. These zones are connected across central Iceland by the Mid-Iceland Belt (MIB). The EVZ includes many volcanic systems, some of which were particularly active in historical times. These are the Vestmanneyjar islands, Hekla, Torfajökull, Eyjafjallajökull, Katla and Grimsvötn.

In this study, we used published geophysical and petrological data to reconstruct the depth of the Moho beneath the EVZ varying from ca. 20 to 25 km b.s.l. [Tarasewicz et al., 2012; Mattson, 2003; Darbyshire, 2000], as well as to define the spatial distribution of the major magmatic storage zones below the EVZ volcanoes. The deepest magmatic reservoir below the recently active Vestmanneyjar Islands (Surtsey and Heimaey) is at 30-35 km, whereas two shallower reservoirs were detected at ca. 20 km and 10-15 km through seismic and magneto-telluric methods [Gebrande, 1980; Mattsson, 2005]. Ground deformation data indicate that the volcanic activity at Hekla, which is located between the EVZ and the South Icelandic Seismic Zone (SISZ), is fed by a 24 km-deep magmatic source. One of the most complex storage systems, made up by multiple reservoirs at variable differentiation degrees, has been recognized at Eyjafjallajökull volcano. Here, the plumbing system extends from ca. 24 km bsl up to 5 km below the summit crater (Sigmundsson, 2010). The Icelandic lithospheric crust gets thicker to 25 km beneath the Grimsvötn - Laki and the Barðarbunga systems in the southeastern part of the island. The Grimsvötn - Laki system is characterized by several magma batches distributed between 30 and 1 km below the summit, which have been selectively reactivated during the historic Laki eruption (1783-84). The Barðarbunga volcanic system is characterized by two deep basaltic reservoirs, with distinct E-MORB and N-MORB signature, and by several shallower batches distributed between 20-22 km and 10 km b.s.l. Beneath Katla volcano, seismic investigations allowed the identification of a single magma reservoir at depth of ca. 2-3 km [Oladottir et al., 2008].

Depths of magma reservoirs related to the EVZ volcanic systems have been also correlated with Fe-Mg diffusion modelling calculations in olivine crystals with the aim to provide a picture of how mechanisms of magma storage and transfer changed along the EVZ, and how they could be influenced by volcano tectonics. Results indicate rather homogeneous timescales of magma migration along the EVZ, which are on the order of 30-40 days for magmas rising up from the upper mantle. Moreover, our petrological data suggest that mechanisms of magma supply are mainly governed by volcano tectonics. This statement is based on the almost totally absence of reversely-zoned olivines associated to the deepest storage zones. Contrariwise, we have evidence of mixing processes involving the slightly more evolved and shallower reservoirs, which

occur with timescales on the order of 1-2 weeks.

Future investigation of processes of magma migration and evolution also along the NVZ and the WVZ are also expected for a proper reassessment of the volcanic risk in Iceland, which should rely on a deep awareness of magma supply dynamics throughout the crust.

S6.16 - Poster

Unravelling volcanic plumbing system dynamics: rates and timescales of magma transfer, storage, and eruption

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Unravelling the rates and timescales of crustal magma transfer, storage, emplacement, and eruption is of paramount importance to better understand subvolcanic processes, characterizing volcanic hazards, and developing mitigation strategies. Here, we review the most relevant open questions in this field. Results highlight long storage timescales in deep (i.e., ~20-30 km) crustal hot zones. Estimated ascent velocities from deep reservoirs to shallower systems span a range of ~10 orders of magnitude, being a function of the thermo- physical parameters of the ascending magma (e.g., density, viscosity, and overpressures in the reservoirs) and the host rocks. At mid- to upper crustal levels (i.e., ~15-20 km), we elucidate the paradigm of cold storage of magma mushes, which can be unlocked during short-term events to form ephemeral magma chambers.
Unlocking timescale estimates range from minutes to kyrs, indicating a variability of about ~8 to ~10 orders of magnitude. This large variation results from the interplay among many processes, often non-linearly coupled, occurring before an eruption. For example, exsolved volatile species have a significant role in controlling pre- eruptive dynamics and relative timescales. They increase the buoyancy of magmas, affect phase equilibria, promote convective dynamics, and may ultimately trigger eruptive events. As a consequence, understanding the role of volatiles in subvolcanic magmatic processes, including ascent rates, storage mechanisms, and relative timescales, will be paramount for future studies.

S6.17 - Poster

Volume-time distribution of eruption units of the last 10 kyrs in Ischia Island (Italy)

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The need to assess the localization and the timing for next eruptions, their typology and their duration are essential questions that the scientific community has to answer. Deterministic forecasting is not possible, so the first step is the characterization of the history of a volcanic system.
In the existing literature about Ischia island, a high-risk volcanic environment, works which combined dataset in order to produce hazard maps, are relatively poor and the analysis are only qualitative and the use of the existent data debatable.
In this work, a volume-time distribution in the last 10 kyrs has been performed, by the volume calculation of each eruption.
Different methodology has been applied for effusive and explosive eruptions. Lava domes and flows volumes have been calculated above the base of the lava by reconstructing the TIN of the vectorialized base, on the basis of the extent identified by de Vita et al., [2010] and according to evidence in the field, DEM and aerial photos. Explosive eruptions volumes have been calculated by a dispersal-based methodology.
Eruptions have been firstly classified in domes and lava flows for the effusive and magmatic, phreatomagmatic, and mixed for the explosive eruptions. The total number of eruptions occurred in the last 10 kyrs is 49, with 34 eruptions in the last 3 kyrs.
From the reconstruction is evident the acceleration in the erupted volumes in the last 3 kyrs, with a relatively decreasing in the number of high magnitude events. The preferred size of eruptive volume has been identified and the role of the last period of quiescence, since 1302 A.D. has been characterized in respect to other periods of quiescence in the past.

S6.18 - Poster

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

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The study of the thermal evolution of pyroclasts is fundamental for the understanding of volcanological processes. For instance, the thermal evolution of pyroclastic density currents directly influences their final run out distance. Similarly, the heat transfer between hot particles and colder ambient air in a convective plume strongly controls the cloud evolution. Since the heat amount available in the system strongly impacts on deposit characteristics, the study of pyroclastic material is fundamental to get information on their thermal history and ultimately reconstruct eruptive dynamics.
In the last decade, few studies dealt with relaxation geospeedometry techniques using a Differential Scanning Calorimeter (DSC) on volcanic materials. This methodology allows to access the thermal history of glassy phases, by revealing the kinetics of cooling across the glass transition. Common DSC devices explore limited cooling rates (below 0.5 K/s) and often need large extrapolations to be applied to cooling rates affecting natural pyroclastic materials.
In this study we introduce the use of a new device, the Flash-DSC, only applied so far in the field of material sciences. Through flash DSC analysis it is possible to widely increase the investigated cooling rates ranging from 3 to 30000 K/s. Therefore, it represents a major improvement for the study of fast- and hyper-quenched glasses, and better captures the cooling rates experienced by volcanic materials following both sub-aerial and submarine eruptions.
We conducted Flash-DSC tests using the so-called “unified area-matching approach”. This methodology uses two heating cycles performed at the same heating rate (in this case 1000 K/s). The second cycle is a cooling-heating matching cycle (always at 1000 K/s). The area-difference between measured heat capacities of the two cycles can be used to determine the fictive temperature of the naturally-cooled glass. A simple relation links the fictive temperature to melt viscosity and cooling rate across glass transition. Therefore, if the viscosity is known, the cooling rate can be retrieved.
Preliminary analysis on standard and synthetic glasses (DGG-1, Diopside and Phosphate) allowed to model successfully cooling rates up to 1000 K/s representing a remarkable improvement for relaxation geospeedometry methodology, with promising implications for the study of volcanological processes and materials, which will be the object of future investigations.

S6.19 - Poster

Experimental study on the rheology of bubble-bearing magmas

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Volcanic activity consists of a wide range of eruptive styles, which are controlled by the gas phase within magmas. The comprehension of the rheological behaviour of these mixtures of melt, crystals and bubbles is primary to understand the physical mechanisms within the volcanic systems. To date, scientific community tried mostly to understand the rheological behaviour of crystal-bearing magmas, due to a minor complexity in performing experiments. Difficulties in the investigation of the bubble-bearing magmas are due to the outgassing of the gas phase from the samples during the experiments. So, while the influence of crystals in magma rheology is better understood, a model for the comprehension of the rheology of the bubble-bearing magmas appears far from being available.
The aim of this work is to understand the complex dependence of the viscosity on vesicles and strain rates, by performing suites of in situ degassing experiments of cylindrical rhyolitic samples at an experimental temperature of 850 °C, followed by uniaxial deformational experiments (constant strain rates of $5*10^{-5}$, 10^{-4} and 10^{-3} s^{-1}) through the Volcanology Deformation Rig [Quane et al., 2004] at chosen experimental temperatures (720-800 °C).
Preliminary results show a complex pattern due to the initial increase of relative viscosity for low amounts of vesicles (0-20%). For higher vesicularities, a non-linear trend of viscosity under the same porosity at different strain rates can be identified: viscosity reaches a peak for a strain rate of 10^{-4} s^{-1}. The general trend shows that, above the 20% threshold porosity, at constant strain rate, the viscosity decreases. There is therefore a complex dependence of the rheological response as a function of the strain rate.
Further investigations will focus on the definition of the rheological behaviour of magmas at a wider range of strain rate, trying to characterize the trend of the viscosity within the ductile regime of deformation.

S6.20 - Poster

Magma - Wall-rock interaction: short term chemical & physical processes and their effects on eruption dynamics

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The interaction of magma with wall-rock is an unavoidable process within the Earth's system. From the generation of the magmas in their source regions and their migration through dykes, sills and conduits, until their final ascent to the Earth's surface, magmas are interacting with the surrounding solid country rock. The most common effects of magma - wall-rock interaction is the erosion of wall-rock, and therefore changes in the geometry of the feeding dyke and the volcanic conduit, and the release of fluid phases through physical or chemical interaction, e.g. CO_2-release during carbon assimilation. Still the interactions of magma with wall-rock are comparably underinvestigated, mostly due to the lack of direct observability of the physical and chemical processes involved.
Experiments at atmospheric pressure were conducted with natural magma and carbonate samples from the Avellino eruption of Mt. Somma-Vesuvius (3945 ± 10yr cal BP), Italy. We plan two different experiments: in the first, a carbonate wall-rock was placed in a crucible and covered with magma; in the second, we added the carbonate wall-rock to the magma already being in the crucible. The relative amounts of CO_2 staying dissolved in the magma, in the bubbles and being outgassed were quantified and the samples were analysed with microtomography.
Previous studies on long-term interactions suggest that the carbon assimilation rate (i.e. how fast a carbonate wall-rock can be assimilated) is mainly dependent on the viscosity of the magma. For relatively high viscosities, the release of CO_2 can lead to local overpressurization of bubbles eventually leading to more pulsating and gas-driven explosions. For relatively low viscous magmas the CO_2-bubble transfer is more effective eventually sustaining an explosive eruption.
There are field evidences that even very short-time interactions (i.e. seconds to minutes) of magma and carbonate wall-rock can lead to increased vesiculation and therefore significantly influence important eruption parameters like degassing, rheology and magma ascent dynamics. The study of the physical and chemical interaction processes is therefore important for hazard assessment.

S6.21 - Poster

Rheological behaviour of particle-bearing suspensions

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The viscosity of magma plays a primary role in forecasting volcanic hazard in active volcanic systems. Chemical (composition and dissolved volatiles) and physical parameters (temperature (T), strain rate and vesicle and crystal contents, including the aspect ratio (A.R.) of the crystals) of magma controls the variation of viscosity within the volcanic conduit. To date, a physical model able to reproduce the rheological behaviour of magma seems far from being available, though several studies have been performed in this attempt.
In this work, we present some preliminary results aimed at modelling the viscosity of round-shaped (A.R. 1) crystal-bearing magmas, based on the four parameters semi-empirical formula, describing the effective relative viscosity as a function of crystal fraction and strain rate, developed by Costa et al., 2009.
The model has been applied to a dataset including most of literature rheological papers, providing a wider variation of the fitting parameters from the equation of Costa et al., 2009. This allows us to forecast the rheological behaviour of crystal-bearing magmatic systems, valid for a wide range of crystal content (1-80%) and under different strain rates (between 10^{-7} and 10^{2} s^{-1}), covering all the strain rates of volcanic activity. The construction of the database allowed us also to collect data with A.R>1, so that we were able to adapt the functional shape of the equation to model systems with crystals having A.R. of 1, 2, 4 and 9 at a strain rate of $5*10^{-4}$ s^{-1}.
One step forward will consist in modelling magmatic suspensions with crystals having an A.R>1 at different strain rates, which is currently in progress.

S6.22 - Poster

Rheological evolution of lava flows: effects of cooling and deformation history on crystallization efficiency and viscous-to-brittle transition

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We present a detailed study on the effects of cooling rate and shear rate on the crystallization kinetics and rheological evolution of a phono-tephrite magma. Experiments were designed to mimic the dynamic conditions experienced by natural flowing lava through controlled cooling-rate and shear rate conditions in a concentric cylinder set-up. Starting from a superliquidus state, a series of dynamic experiments were performed under: i) different cooling rates (from 1°C/min to 20°C/min) at constant shear rate (5 s-1) and ii) variable shear rates (from 0.1 s-1 to 20 s-1) at constant cooling-rate (1Â°C/min). All experiments were terminated at various degree of undercooling related to the different experimental conditions, when the cut-off temperature ($T_{cut\text{-}off}$) representing the magma complete solidification (i.e., "rheological death") or brittle response was reached.

In controlled cooling-rate experiments, a minimum of 10°C/min is needed to activate crystallization. At higher cooling rates > 10Â°C/min) crystallization is suppressed due to strong disequilibrium (unrelaxed) melt conditions. At lower cooling-rates (from 1 to 10°C/min) the onset of crystallization and viscous-to-brittle transition occur at higher temperature with decreasing cooling rate value.

In controlled shear rate experiments, the effect of stirring strongly promotes crystallization by shortening nucleation incubation time. As a consequence, crystallization onset and viscous-to-brittle transition is achieved at higher temperature (only for strain rates >1 s-1).

Results indicate that both thermal and deformation histories exert a primary control on the kinetics of the crystallization process, on the magma rheological evolution and hence modulate the lava flow capability. In particular, both strain and cooling rates play a fundamental role on the viscous/brittle threshold that is responsible, for instance, of the transition of lava surface morphology from pahoehoe to aa.

S6.23 - Poster

Sedimentation processes in pyroclastic density current through numerical modelling approach

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Pyroclastic density currents (PDCs) are the most destructive phenomena associated with volcanic eruptions. Despite our knowledge of the sedimentological characteristics of PDC deposits, and the recent advances in laboratory experiments, our comprehension about the flow and their dynamics are still incomplete. Furthermore, we do not yet understand how to interpret or translate the sedimentary records of pyroclastic density current deposits in a way to quantify the parental flow conditions. The aim of this work is to quantify, through numerical modelling, the internal PDC dynamics, to characterize their transport and deposition processes.
To date, several critical issues arise with numerical simulation of PDCs, which involve a multiphase gas-particle fluid whose dynamics evolve over a wide range of scales, involve a complex non-linear rheology, and moves over a three-dimensional topography. In this work, we have tested a new multiphase flow model able to consider frictional to collisional particle rheology to describe both the concentrated (basal) and dilute portions of a PDCs. The numerical model is able to tackle with complex 3D geometries with local mesh refinements, allowing us to perform simulations over realistic topography without an excessive computational cost. This model was first verified using two simples' cases as testing data. Then, it was applied to eruptive scenarios of the Soufrie're Hills Volcano, Montserrat. Flow runout, sediment concentration and effect of the topography on the propagation of PDCs were simulated in this case. Benchmark cases are illustrated, to verify and demonstrate the main features of this model. Potential application to problems of volcanic hazard assessment are finally discussed.

S6.24 - Poster

The welding ability of pyroclastic deposits: insights from an experimental study on the interclast viscosity contrast

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During welding, pyroclastic deposits show a complex rheological behavior mainly controlled by the relative contributions of emplacement temperature, load (i.e., accumulation rate) and glass transition temperature. In this framework, the effect of the presence and nature of different lapilli-sized clasts embedded within the ash-matrix is not well constrained. Here we present a set of high-temperature deformation experiments on confined cores of loose ash and lapilli of different composition to reproduce the welding process of pyroclastic deposits made of particles of different size and nature (as crystals, lithics and juvenile). The textures produced by these experiments are comparable to welding natural textures, showing for example the alignment of ash shards and the flattening of pumices (fiamme). The presence of lapilli generated an immediate reaction to the increasing stress, with an increase in viscosity up to the 0.05 of strain. With increasing deformation, the strain is then dissipated in both the ash matrix and the lapilli fractions, with the formation of fiamme. Lapilli with the highest viscosity, higher than the ash matrix, react as rigid bodies and they are undeformed, equivalent to undeformed lithics in pyroclastic welded deposits. During the deformation, the samples accommodate the strain by porosity loss, since radial bulging is inhibited by the confined set-up of the experiments. At the same time, the confined geometry strongly favors the onset of bubble overpressure, primarily controlling the resultant effective viscosity, that can exceed in some cases the viscosity of the non-porous ash matrix. Therefore, we suggest that for the modelling of welding processes in natural pyroclastic bodies, the effect of bubble overpressure, as well as the different nature of pyroclastic materials should not be disregarded.

S6.25 - Poster

S7. THE NATURE OF THE MANTLE: GEOCHEMICAL AND MINERALOGICAL COMPOSITION VERSUS PETROLOGICAL PROCESSES

Conveners:
Alessandra Correale (INGV-PA), Vincenzo Stagno (UniRM1), Costanza Bonadiman (UniFe)

Redox estimates through trace elements partitioning: application on two Italian volcanoes

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Redox conditions of magmas sources can be considered as one of the most complex issues of petrology [Carmichael, 1991; Evans, 2012]. Oxygen fugacity (fO_2) controls the speciation and behaviour of multivalent elements (i.e. Fe^{2+} and Fe^{3+}) during mantle melting and mineral crystallization. The strong dependence of the vanadium partitioning between olivine and silicate melt on redox conditions is demonstrated by many studies [Canil, 1997; Canil and Fedortchouk, 2000; Davis et al., 2013; Laubier et al., 2014; Mallmann and O'Neill, 2009, 2013; Shishkina et al., 2018; Wang et al., 2019], and it allows to use the vanadium partition coefficient ($D_V^{Ol/melt}$) as sensitive oxybarometer in magmatic systems.

With the objective to compare the redox conditions of the mantle associated to different geodynamic systems, we applied available oxybarometers, involving vanadium, to two basaltic products: FS eruption from Mt. Etna [Coltelli et al., 2000, 2005; Kamenetsky et al., 2007; Correale et al., 2014] and Vateliero eruption (VAT) from Ischia Island [D'Antonio et al., 2013; Moretti et al., 2013]. These two eruptions, dated 4000 (FS) and < 2600 (VAT) years B.P., respectively, have been selected as considered among the most primitive of the studied volcanic systems. Being the olivine crystals in equilibrium with the magma from which have been crystallized, the measurements of the olivine-melt partition of vanadium allowed us to trace the redox conditions existing when the olivine crystals were formed.

To achieve this goal, extensive analysis of the major and trace components of olivine and melt inclusions were conducted by Electron Probe Micro-Analyzer at the Institut des Sciences de la Terre d'Orléans (ISTO) and by LA-ICPMS technique at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) - Palermo.

Our results suggest that the average redox conditions of Mt. Etna magma source attest at NNO+1.8 (±0.25) (where NNO is a Ni-NiO oxygen buffer and the numbers refer to the log units of fO_2 deviation from the buffer). These results are in according to previous works where ΔNNO>+1 was reconstructed by Cr-spinel composition [Kamenetsky and Clocchiatti, 1996] or S6+/Stot up to NNO+1.8 [Métrich et al., 2009]. Ischia results show more oxidized conditions than Etna, as expected for subduction-related magmas [Mungall, 2002; Kelley and Cottrell, 2009; Brounce et al., 2014]. Indeed, compared to the typical intraplate magmatism, slab-derived components containing H_2O should oxidize the source mantle wedge. Results obtained for the source of Ischia magmas are attested at NNO+2.1 (±0.3) and are comparable to those from a previous work [NNO+2 up to NNO+3; Moretti et al., 2013].

S7.1 - Presentazione orale

In situ Mössbauer spectroscopy of coexisting spinel and clinopyroxene of clinopyroxenites from the Hyblean plateau

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The knowledge of the global Earth's mantle oxidation state is needed to model the speciation of C-O-H volatiles and the role that these might have on deep melting processes through time [Stagno et al., 2019]. The mantle redox state is commonly determined through the use of oxy-thermobarometers that require the accurate measurements of ferric and ferrous iron of redox sensitive minerals like spinel and clinopyroxene whose crystal chemistry is known [Stagno, 2019]. To date, however, no oxy-barometer has been tested to calculate the oxygen fugacity of clinopyroxenites.
In this study, we determined the iron oxidation state of coexisting spinel and clinopyroxene pyroxenite xenoliths host in the Miocene Hyblean tuff-breccia pipe of Valle Guffari (Sicily, Italy). The ferric iron content of clinopyroxene and spinel single crystals was determined by in situ synchrotron Mössbauer source spectroscopy (SMS) at the Nuclear Resonance Beamline [Rüffer and Chumakov, 1996] ID18 of the European Synchrotron Radiation Facility (ESRF, Grenoble, France) using the 111 Bragg reflection of a 57FeBO3 single crystal mounted on a Wissel velocity transducer driven with a sinusoidal wave form [Potapkin et al., 2012] at room temperature. The X ray beam was focused to an area of 15x10 microns using Kirkpatrick-Baez mirrors. The velocity scale was calibrated using 25 microns thick natural α-Fe foil. Spectra were fitted using a full transmission integral with a normalized Lorentzian-squared source lines shape using the MossA software package [Prescher et al., 2012]. Mössbauer were collected within about 1-2 hrs.
Preliminary results show that the measured $Fe^{3+}/\Sigma Fe$ ratio in spinel falls within the range of typical spinels from mantle rocks [Stagno, 2019]. In addition, the ferric iron content of both spinel and cpx are here used to determine their crystal chemistry. Our data will be used 1) to model the relation between ferric iron of spinel and clinopyroxene, 2) to compare our measurements of ferric iron of clinopyroxene with those available in literature and 3) to test a potential oxy-thermobarometer for clinopyroxenites supported by thermodynamic models and experimental data [Luth and Canil, 1993].

S7.2 - Presentazione orale

Iron-rich tourmaline breakdown at high pressure and temperature as potential source of metasomatic B-rich fluids in the mantle

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Boron is among those light elements that are considered to act as contaminants of the Earth's mantle through metasomatic fluids [Palmer and Swihart, 1996; De Hoog and Savov, 2017]. The presence and abundance of boron in fluids has been widely related to its incorporation and abundance in serpentinite rocks [Tenthorey et al., 2004], hydrous minerals like phengite [Hermann et al. 2013] and lawsonite [Vitale Brovarone et al., 2014] through breakdown processes during subduction. However, the finding of tourmaline within assemblages of UHP metamorphic [Lussier et al., 2016; Korsakov et al., 2019] rocks suggests a possible role of borosilicate minerals in the origin of B-rich fluids at high pressure and temperature. Tourmaline from metamorphic assemblages can contain up to ~14 wt% B_2O_3 (i.e. > 80 wt% of the whole-rock B), ~4 wt% H_2O and ~2 wt% F, representing an important carrier of volatile elements.
In this study we explored the possibility that B-rich fluids might form as consequence of redox-driven decomposition of tourmaline at high pressure and temperature.
We investigated the structural stability of natural schorl tourmaline with ~19 wt% FeO. The experiments were performed using the Walker-type multi anvil press (840t) at a fixed pressure of 1 atm, 3.5 and 6 GPa and temperatures between 500-1000 °C with duration between 2 and 10 hrs. The fo_2 in these experiments was internally buffered by adding 20 wt% of either Re+ReO_2 (1:1 mole ratio) or $Ag_2C_2O_4$ and graphite. The recovered quenched products were then polished and analysed by scanning electron microscopy, electron microprobe and X-ray (powder?) diffraction for both textural and chemical characterization.
Our preliminary data show a gradual decrease schorl within the investigated experimental conditions, resulting into a gradual increase of Si and Fe as consequence of the crystallization of new tourmaline, unknown volatile-bearing phases and Al-rich phases also like kyanite, mullite, corundum and almandine garnet as a function of increasing temperature. Additional phases like Fe-rich jadeitic pyroxenes might form as result of oxidation of Fe^{2+} to Fe^{3+} of the starting material.
Our experiments provide an experimental evidence of the gradual release of water and B through structural weakening of Fe-rich tourmaline and offer an alternative explanation regarding the origin of B-rich fluids at local scale upon subduction at high pressure and temperature.

S7.3 - Presentazione orale

Experimental constraints on mobility of volatile-bearing magmas and timing of melt-rock interaction in the Earth's upper mantle

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Magmas produced at pressures, temperatures and redox conditions of the Earth's upper mantle are characterized by a large amount of volatiles such as CO_2 and H_2O. In fact, magmas formed by low degree of partial melting of carbonated rock assemblages can contain CO_2 amount as high as 40 wt% and H_2O up to 4 wt% as testified by mineral-hosted melt inclusions [e.g. Green, 2015]. These magmas play a key role for the chemical heterogeneities observed at mantle conditions [e.g. Hauri et al., 1993; Coltorti et al., 1999]. Whether they stagnate at depth, leading to extensive melt-rock interaction (i.e. metasomatism), or sustain the feeding system of active volcanoes depends on their rheological properties with respect to the surrounding mantle.
We investigated experimentally the viscosity, melt structure and chemical composition of liquidus minerals of a suite of volatile-bearing mantle melts ranging in composition from carbonate-silicate to CO_2 and H_2O-bearing ultrabasic and basaltic melts. Experiments were carried out at pressures of 0.4-6.3 GPa and temperatures between 1050 and ~2000 °C using the Paris-Edinburgh press (PEP) combined with synchrotron radiation at beamline 16 BM-B of HPCAT (Advanced Photon Source, Illinois, USA). Viscosity measurements were performed using the falling sphere technique by means of in situ ultrafast radiography to record a series of X-ray images necessary to track the fall of a platinum sphere through the liquid sample and calculate viscosity by using the Stokes law. Melts in the PEP were further investigated by multi-angle energy dispersive X-ray diffraction technique (EDXD) with a 2-theta angle ranging from 3° to 35° to determine the structure factor and interatomic distances as a function of pressure, temperature and chemical composition.
Results obtained show viscosities from 0.02 Pa·s for carbonate-silicate melts that increase up to two orders of magnitude in the case of ultrabasic and basaltic melts. This was attributed to the progressive formation and connection of silicate tetrahedra as the abundance of network formers such as Si4+, Al3+ in the melt increases and confirmed by structural changes at atomic scale.
Our viscosity data allowed the calculation of the hydrostatic melt mobility, proportional to the gravity-driven melt transportation, which was estimated to vary from ~60 to 0.2 $g·cm^{-3}·Pa^{-1}·s^{-1}$ within the compositional range presented in this study and to model their migration rate through mantle lithologies as a function melt fraction, grain size, chemical composition and depth. Calculations suggest that, despite fast timing of mantle infiltration by the more volatile-rich and SiO_2-poor melts, their migration upward results in long residence times due to porous flow regime and low melt fractions involved. We will discuss further results applicable to natural volcanic systems such as Mt. Etna and Alban Hills.

S7.4 - Presentazione orale

Combined effect of the degassing and diffusion process in the variation of the ratios of $^{3}He/^{4}He$ and $^{4}He/^{40}Ar^{*}$ in the fluid inclusions of the phenocrystals of the products of Mount Vulture

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Mount Vulture is a Pleistocenic volcanic complex located in the southern part of the Apennine chain (Italy). Its last eruption occurred ~140ka ago. Its products have peculiar petrologic characteristics, not least the trace element pattern and isotopic features that are intermediate between intraplate and subduction-related signatures. Hence, its magmatism is different from Italian Quaternary volcanoes that are characterized by affinities related to subduction. Furthermore, it is located at the eastern border of the Apenninic front far from peri-Tyrrhenian volcanoes and its origin and magmatism are matter of debate [Peccerillo, 2017 and references therein]. The differences between Mt. Vulture magmatism and peri-Tyrrhenian ones could be justified by different magmatic sources feeding volcanism in the Italian peninsula. Here we are going to discuss about new helium (He) isotope data, together with the Ne and Ar isotopic signature, in fluid inclusion of pyroxenes and olivine phenocrysts of most the Mt. Vulture volcanites, in order to constrain the features of the mantle source during its eruptive history. The $^{3}He/^{4}He$ ratio of the samples varies from 2.83 to 6.74 Ra (Ra is the $^{3}He/^{4}He$ in atmosphere, $1.39x10^{-6}$) and the $^{4}He/^{40}Ar$ ratio varies from 0.63 to 33.16. This variability has been interpreted as subduction-type effect or heterogeneity of the mantle source [Caracausi et al., 2013]. Ne isotopic signatures overlap the air composition and some samples show Ar isotopic signature different from air. Magmatic processes (e.g., diffusive fractionation and magmatic degassing) can also explain the variability of the $^{3}He/^{4}He$ ratio and of the noble gases relative abundance (e.g., $^{4}He/^{40}Ar$). Indeed, the degassing process, the outgassing process combined with the mass-dependent fractionation, after volatile trapping and during magma residence in the plumbing system prior to eruption, can produce variations in the $^{3}He/^{4}He$ and $^{4}He/^{40}Ar^{*}$. This can occur during disequilibrium open-system degassing of the erupting magma He and Ar diffusion through the phenocrysts within sub-solidus magma conditions. Several studies have previously modelled He isotope fractionation due to the faster diffusion of ^{3}He than ^{4}He, moreover both of them are faster in the diffusion than Ar (temperature-dependent process). Assuming an Arrhenius temperature dependence, a slight He isotopic fractionation can be observed (up to 15% at 1200°C) [Trull and Kurz,1993] and by vacancy diffusion mechanisms theory, the Ar diffuses up to 3.16 times slower than helium. Using the same approach, we calculate the fraction of lost He and the effect on the $^{3}He/^{4}He$ and on $^{4}He/^{40}Ar$. Calculated values well fit with unique mantel source can explain the high variability of $^{3}He/^{4}He$ at Vulture volcano.

S7.5- Presentazione orale

Gas and rock geochemistry at Karthala and La Grille volcanoes (Grand Comore Island, Indian Ocean): Preliminary results

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Grand Comore is the youngest island of the Comoros volcanic chain (western Indian Ocean) and it is located between Madagascar and East Africa. It is composed by two shield volcanoes, La Grille and Karthala, this latter recording the last volcanic activity in 2007. Karthala volcano is one of the most active volcanoes of the Indian Ocean (together with Piton de la Fournaise at La Reunion Island) and produced at least 34 eruptions since 1800 with a strong societal impact. Magmatic and active seismicity along the Comoros volcanic chain have been attributed either to the activity of a mantle plume and/or to rifting. In 2017 and 2018, we performed two geochemical surveys on Grande Comore, through fumarole gases, rock sampling and CO_2 flux measurements from soil. The two main fumarolic areas are at the volcano top (Soufrière and Choungou-Chagnoumeni). These areas occur along the main area (northern rift) of anomalous CO_2 flux on Grande Comore Island. Collected fumaroles had a maximum temperature of 96°C. The fumarolic gases are CO_2-dominated. We report the first measurements of the helium (hereafter He) isotopic signature in the fumarolic gases that are up to 5.8 Ra (Ra being the He isotopic signature in air) but lower than the typical MORB range (Mid Oceanic Ridge Basalts, 8Ra). These values overlap those measured in olivine phenocrysts from Karthala products (from 5.1Ra to 6.3Ra; Class et al., 2005), indicating that Karthala volcano is still degassing volatiles with a He isotopic signature that is in the range of those in volcanic products of the last eruption. Here we also report the first data of carbon isotope signature of CO_2 in fumarolic gases that vary from -5.0 to -3.9‰ and fall in the typical range of mantle-derived material. The diffusive CO_2 flux measurements allowed recognizing that an active degassing occurs along the main tectonic discontinuities that cross the Karthala volcano. The highest volcanic CO_2 fluxes have been measured in the Karthala crater. Ultramafic mantle xenoliths from the La Grille alkaline volcano have been studied with the aim at characterizing the mantle below Grande Comore Island. Olivine, clinopyroxene and orthopyroxene (hereafter Ol, Cpx and Opx) crystals were analyzed for noble gas (He, Ne, and Ar) and radiogenic isotopes (Sr, Nd, and Pb) measurements. The He isotopic signature in fluid inclusions (up to 7.4Ra) in olivine, clinopyroxene and orthopyroxene is in good agreement with that from literature [Class et al., 2005] and falls in a range that overlaps the SCLM (Sub Continental Lithospheric mantle) and the MORB mantle signature. Here we report the first ever Ne and Ar isotope data on the fluids and enclaves of Grande Comore whose ratios are indistinguishable from those of volatiles in typical MORB-type mantle reservoirs. He isotopes in volatiles from Karthala fumaroles and fluid inclusions are lower than La Grille values suggesting that a) the mantle sources feeding Karthala and La Grille volcanism are heterogeneous and/or b) additional processes modify the pristine signature of the mantle-derived volatiles emitted at Karthala volcano. The preliminary results of Sr-Nd-Pb systematic in Opx and Cpx from the La Grille xenoliths show higher variability than La Grille bulk lavas [Class and Goldstein, 1997; Class et al., 1998]. As a whole, Cpx and Opx samples have Sr-Nd isotopic ratios that fall along a mixing between Depleted Morb Mantle and Enriched Mantle reservoirs.

S7.6 - Presentazione orale

Interaction between mafic mantle-derived and silicic magmas in Central Italy: the case study of the Radicofani-Amiata Volcanic System

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The Radicofani-Amiata volcanic system characterised by two main periods of activity: 1) an early period characterised by the eruption of the Radicofani monogenetic volcano, between 1326 and 1299 ka, and 2) a late period in which a renewal of volcanism brought to the built up of the Monte Amiata volcano, between 305 and 231 ka.
The main petrographic characteristics of the Radicofani-Amiata Volcanic System are represented by the occurrence of:

- mantle derived olivine-bearing basaltic andesite to shoshonite lavas and scoria at the Radicofani monogenetic volcano;
- basal trachydacitic rocks derived by differentiation from the Radicofani mafic magmas, characterised by the presence of abundant upper crust xenoliths and rare rounded magmatic enclaves;
- massive lava flows and domes ranging in compositions from trachydacite to trachyte, latite and olivine latite, with an incremental abundance of rounded mafic magmatic enclaves with decreasing emplacement age;
- final mafic olivine latitic lava flows with rounded micaceous magmatic enclaves beside the mafic ones.

Monte Amiata massive lava flows and domes display large sanidine megacrysts set in glassy groundmasses. Peculiarly, rounded mafic enclaves continue the linear correlations observed among Monte Amiata rocks pointing to a possible undisclosed mafic, silica-undersaturated end member.
The occurrence of rounded magmatic enclaves testifies the occurrence of a process in which the fresh mafic hot magma was injected in a cooler and partially crystallised differentiated one, which partially mixed and mingled. The arrival of mafic magma within the differentiated magma reservoir triggered the pouring out of the viscous trachydacitic resident magma derived by the early Radicofani basaltic andesite. 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 final olivine-latites. The same timely reverse differentiation pathway is observed among magmatic enclaves, with the most mafic terms hosted by final olivine-latitic lava flows. Fine-grained rounded magmatic enclaves, indeed, range in composition from potassic trachybasalt (absarokite) to olivine-latite.
Geothermobarometric calculations on mineral-liquid pairs (e.g., plagioclase-liquid, clinopyroxene-liquid, and olivine-liquid) provide the P-T conditions range of the Radicofani-Amiata magmatic reservoir.
The overall geochemical and isotopic features agree with a mixing process between a highly differentiated (i.e., high silica) and partially crystallised, high-K calc-alkaline magma and a mafic

ultrapotassic one, possibly leucite-bearing. The absence of leucite in the less differentiated enclaves is likely due to crystallisation depression of silica undersaturated minerals due to the high-silica activity imposed by the high-silica end member.

Sr-Nd-Pb and trace element distribution are compatible with the occurrence of two mantle derived mafic end members in the Radicofani-Amiata system. An early silica saturated calc-alkaline to shoshonitic mafic magma that produced the differentiated Amiata trachydacitic rocks and a late mafic silica-undersaturated magmas, similar to that of Monti Vulsini, that mixed and mingled within the upper crust to define the entire compositional spectrum of Amiata rocks and enclaves. These data support the occurrence of a transition, during the Pleistocene, from silica-saturated to silica-undersaturated magmas production by partial melting of the upper mantle beneath Central Italy possibly due to arrival of a CO_2-rich metasomatic agent.

S7.7 - Poster

Spinel-bearing mantle xenoliths and basic-ultrabasic magmas with garnet signature: a revision of the mantle sources of Veneto Volcanic Province (Northeastern Italy)

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The Veneto Volcanic Province (VVP; e.g., [Beccaluva et al., 2007]), in northeastern Italy, is one of the widest Cenozoic magmatic districts of Adria microplate located near the Alpine chain. From late Paleocene to early Miocene, during the Alpine orogeny, the VVP magmatic activity developed within several volcanic districts: Val d'Adige, Lessini Mts., Marosticano, Berici Hills, and Euganean Hills. The VVP magmas span dominant alkaline to rare sub-alkaline compositions including ultrabasic, basic, intermediate, and acid rocks. The least evolved magmatic products have trace element signatures typical of intraplate magmas (e.g., high HFSE contents, high LREE/HREE ratios, and relatively low LILE/HFSE ratios [Beccaluva et al., 2007; Brombin et al., 2019]). Different interpretations were given to explain the occurrence of this intraplate-related magmatic activities near a subduction zone. Macera et al. [2003, J. Geodyn.] suggest mantle upwellings through slab window(s) after the European slab break-off, which occurred at ~ 35 Ma. In this context, mantle flow upwelling would have induced the decompression melting of a spinel-lherzolite mantle source. This hypothesis seemed confirmed by the spinel peridotite mantle xenoliths carried by nephelinites and basanites, which were interpreted as remnants of the potential VVP mantle source by several authors. In particular, Beccaluva et al.2001 and Brombin et al. 2018 invoked a spinel lherzolite enriched with hydrated carbonated components as source for VVP magmas, to justify the deviations of VVP samples from typical OIB trace element patterns. However, recently a new geodynamic model has been proposed considering new geophysical evidences for an unbroken subvertical European slab [Hua et al., 2017] and new geochronological evidence for onset of VVP magmatism in the late Paleocene, i.e., before the supposed slab break-off [Brombin et al., 2019]. The roll-back of the European slab probably induced the sub-slab mantle material escape and its upwelling from the front of the slab, which may have triggered intraplate magmatism and extensional deformation in the overriding Adria plate [Brombin et al., 2019]. In this new geodynamic framework, considering the upwelling of deep mantle, decompression melting of sources located at shallow depth in the spinel stability field are unlikely. Consistently, trace element patterns and ratios of a new suite of VVP basic-ultrabasic rocks, in particular their steep M-HREE profiles suggest a possible presence of garnet in the mantle source. Moreover, these basic-ultrabasic magmatic products exhibit i) depletion in K and Rb, pointing to the presence of a residual K (Rb)-bearing phase (i.e., amphibole and/or phlogopite) in the mantle source and ii) enrichments in Ba, Sr, and P, and depletions in Zr, Hf, and Ti, suggesting signature of carbonatitic metasomatic enrichments. Therefore, VVP basic-ultrabasic magmas may be formed by ~1.5-4% degrees of partial melting of a carbonated phlogopite-bearing garnet peridotite mantle source. The carbonatitic metasomatic agent of the VVP mantle source was possibly derived by the breakdown of carbonates of metasediments dragged at depth by the subducting Tethys slab. Probably, during the ascent of the mantle flow spinel peridotites were removed and ferried to the surface. Therefore, this study provides a revision of the nature and evolution of VVP mantle source, which was indirectly influenced by the subduction events, with melting occurring probably in the garnet stability field.

S7.8 - Poster

Trace elements and noble gases (He, Ne, Ar) isotopic study of Fuerteventura carbonatites: implications for their mantle source

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Carbonatites are very rare in oceanic environments and in the Atlantic Ocean they can be only found at Fuerteventura (Canary Islands) and Cape Verde islands [De Ignacio et al., 2006]. Fuerteventura is located on a transitional, oceanic to continental, crust (Moho depth ≈20 km), due to the proximity to the African Plate [Arevalo et al., 2013]. This volcanic island consists of Mesozoic sediments, basalts and trachytes, ultramafic to felsic intrusives and carbonatitic dike swarms. Ca-carbonatites (sövite) and their related alkaline-silicate rocks (clinopyroxenites, melteijites-ijolites, nepheline-sienites, sienites) crop out along the western coast of Fuerteventura. Mineralogy consists of calcite, aegirine-augite, albite, K-feldspar, biotite, apatite, Fe-Ti oxides and accessory minerals, such as zircon, barite, monazite and pyrochlore. This research shows new measurements of trace elements and, for the first time, noble gases data in fluid inclusion of carbonatitic complex minerals from Punta de la Nao (Fuerteventura).
Trace elements were determined by LA-ICP-MS on calcite and pyrochlore. Results show that pyrochlore is the main mineral repository of REEs (sum REE = 21.7 wt %), with very high LREE La_N = 71214 and Ce_N = 62803 (chondrite normalized) with respect to HREE (Yb_N = 997, LuN = 695) and a slightly steeper pattern $(La/Yb)_N$ = 71 if compared to calcite (La/Yb)N = 58. Calcite phenocrysts REE patterns are highly enriched in all REEs (sum REE= 1186-2943 ppm). Small negative Eu anomalies do also occur (Eu/Eu* = 0.77 - 0.94) and these are coupled with high Sr anomalies (Sr/Sr* = 28.3 - 58.7).
The field relationships of the carbonatites suggest that they represent the latest intrusive event of the alkaline-carbonatitic complex (age 25 Ma), although they are almost contemporary with other related alkaline-silicate rocks [Muñoz et al., 2005]. More primitive rocks are represented by clinopyroxenites from a mafic-ultra mafic complex (Mezquez), remnants of magma chambers that have fuelled Miocene magmatism, as resulted from noble gases (He, Ne, Ar) isotopic study, performed by crushing clinopyroxenes (augites) separates from clinopyroxenites. Calcites and clinopyroxenes from carbonatites (Ajuy, Punta de la Nao) were also analysed.
Trials carried out in clinopyroxenes from clinopyroxenites reveal the presence of $^3He/^4He$ ratios ≈ 6.66 Ra (Ra is the He isotopic signature in atmosphere); clinopyroxenes analyses from carbonatites show low $^3He/^4He$ ratios (≈ 2.23 Ra), while calcites $^3He/^4He$ ratios are a little higher (≈ 3.87 Ra). $^4He/^{20}Ne$ ratios in clinopyroxenes from clinopyroxenites and carbonatites are respectively 1120.7 and 1582.6. Calcites values of $^4He/^{20}Ne$ ratios in carbonatites are higher than 500. These elevated values of $^4He/^{20}Ne$ ratios in the studied samples exclude any He atmospheric contamination. The values of He isotopic ratio (6.66 Ra in the clinopyroxenites) are lower than the typical MORB mantle source (8 Ra ± 1), and it is in the range of the Sub Continental Lithospheric Mantle (SCLM, 6.1 Ra ± 0.9). However, the Ne isotopic signature in the same samples is indistinguishable from the air composition and in contrast the Ar isotopes are well-solved respect to those from a mantle source.
Isotopic studies in carbonatites have been specifically focused on the resolution of (i) the petrogenetic process that originate carbonatites, where a close relationship with their associated

alkaline silicate rocks is usually implied. The abovementioned studies have been focused as well on (ii) the mantle source(s) potentially involved in their petrogenesis.
Preliminary results show that $^{3}He/^{4}He$ ratios are slightly lower than typical MORB mantle values and suggest that Fuerteventura carbonatitic magmas originated in a modified mantle, probably by past subduction events and some processes changed their original composition of the $^{3}He/^{4}He$ ratios and their magmatic primary fingerprint.

S7.9 - Poster

S8. ADVANCES IN GAS AND ASH OBSERVATIONS OF EXPLOSIVE VOLCANIC ERUPTIONS OF VARIABLE INTENSITY AND CORRELATION WITH ERUPTION STYLES

Conveners:
Stefano Corradini (INGV-ONT), Claudia D'Oriano (INGV-PI), Giuseppe Salerno (INGV-OE), Pietro Gabellini (UniFi), Frank Marzano (UniRM1)

Eruptive dynamics and fragmentation mechanisms of vulcanian activity at Sakurajima volcano (Japan): insights from the quantitative investigation on ash shape and texture

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Since many years, the study of products associated to ash-dominated eruptions has grown continuously. Morphological and textural features of volcanic ash are considered as an important tool to investigate the dynamics of explosive activity, particularly that characterized by high-transients both in style and intensity. Ash features like shape and internal texture of grains are proved to efficiently record changes in magma properties, from its ascent into the conduit until fragmentation, and give first-hand insights onto the dynamics controlling the fragmentation mechanisms. Secondary processes, like the prolonged transport into volcanic clouds, or intra-crateric recycling of juvenile material, are important in modifying the ash features, and their effects are often superimposed on the original matrix.

The recent activity of Sakurajima volcano (Japan), lasting almost continuously from 1959, is well known for being characterized by high-transients both in style and intensity of the eruptive activity, and for this reason it was selected here as a case-study to investigate the relations between the styles of activity and the processes of ash formation. Cycles of vulcanian explosions commonly repeat at Sakurajima, starting with continuous and low intensity ash puffing to weak ash emission not associated to explosive activity, followed by ash dominated, strong Vulcanian explosions and closed by prolonged phase of ash venting. At present, these cycles are generally repeating at a rate of 1 or 2 large explosions every few days.

To understand the complex relations existing between the eruptive dynamics and the conduit processes controlling the eruption, we investigated the texture and the external shape of thousands of ash fragments resulting from the whole cycle of a large vulcanian explosion observed at Sakurajima volcano during 2014. The resulting ash samples have been analyzed and compared in order to understand the mechanisms controlling ash formation and the eruptive dynamics as well. The links existing between the intra-eruptive dynamics and magma fragmentation processes have been discussed analyzing the variations of the main physical characteristics of the ash during the different eruptive phases. As a result, the large database of morpho-textural information on ash allowed us to interpret the observed eruptive dynamics in terms of the conduit processes that accompanied the eruption during the different phases of the vulcanian cycle. These appeared as mainly regulated by the continuous degassing and consequent pressure accumulation at the top of a rigid and viscous magma column, whose upper portions tend to be destructed and partially removed during stronger vulcanian explosions.

S8.1 - Presentazione orale

A multi sensor system for detection and monitoring of volcanic ash

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Within the framework of Ash-RESILIENCE, project funded by "Ministero dell'Istruzione dell'Università e della Ricerca" (MIUR), we are performing an innovative and extremely low cost, low energy consumption and small size wireless electronic multi-sensor system for the detection and monitoring of volcanic ash in sensitive and urban areas (highways, airports, etc.), in order to manage information and alerts caused by ash fallout in the best way. From a technical and practical point of view, we want to implement a Wireless Sensor Network in order to record, process and share data acquired to monitor large areas affected by ash fallout. Collected data will be available through remote access connecting the system directly to the acquisition center at INGV-OE (in wireless mode), and establishing a cellular communication system.
We will employ a ready to use and low energy consumption "single-board computer" (SBC), such as Raspberry Pi, Arduino or Nvidia Jetson Nano, to obtain an embedded device with appropriate computational power without influencing system costs and dimensions. SBCs will be equipped with the versatile and stable LINUX OS such as Raspbian.
The main challenges are:

- decreasing the overall complexity of the system using fewer sensors and mechanics to maximize reliability;
- promoting innovative software solutions, using powerful open source image processing tools.

We are developing an algorithm for ash detection to receive alerts and monitoring data when the ash amount in the ground exceeds a pre-specified value of interest.
To distinguish images pixels into two classes data, background (white collecting surface) and foreground (dark ash particles), we determine an automatic gray scale image thresholding, which adaptively finds the optimal image threshold. This threshold is identified by minimizing intra-class pixel intensity variance, or equivalently, maximizing inter-class variance. In our opinion, this is the best approach to carry out the binarization of bi-modal images to get dependable information starting with the ash pictures acquired inside our devices.
Measuring the ash weight in a remote and reliable way is a further key challenge, even more for small size devices, for volcanic surveillance purposes. Therefore, the next goal will be integrating into algorithm the innovative method "Pixel Digital Weight" we conceived, to accurately measure the ash weight, which does not require sophisticated scales and sensors, but only a low-cost Full HD visible and/or IR camera.

S8.2 - Presentazione orale

Interpreting and exploiting radar reflectivity at L-band and X-band for the tephra mass retrievals of the 2013 and 2015 Etna paroxysms

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Mt. Etna, located on the east coast of Sicily (Italy), is one of the most active volcanoes in Europe. The most distinctive phenomena associated with the activity of Etna are represented by lava fountain paroxysms generating volcanic plumes, sometimes characterized by a significant tephra discharge rate (e.g., [Andronico et al., 2015; Corsaro et al., 2017]). Paroxysms at Etna mostly consist of sustained jets of fluid lava, propelled into the atmosphere from summit craters or lateral vents and driven by expanding gases, which commonly occur at basaltic volcanoes [Calvari et al., 2011]. The coeval magma fragmentation gives rise to tephra plumes ascending to altitudes up to 15 km a.s.l.

Weather radar scanning systems can be exploited to monitor a volcanic plume in 3-D, measuring the reflectivity due to small lapilli and coarse ash at a fairly high spatial resolution (less than a few hundred meters) and every few minutes [Marzano et al., 2006 a, b]. Weather radars can provide data for estimating the plume tephra volume, total mass and height using the volcanic ash radar retrieval (VARR) method for single- and dual-polarization systems at S, C and X band [Marzano et al., 2013; Marzano et al., 2016; Mereu et al., 2015]. A Doppler fixed-pointing radar at L band (VOLDORAD-2B), oriented towards the volcano summit craters, is able to follow the plume column dynamics in real time at high rate (0.2 s) providing both tephra power returns and Doppler velocities mainly due to lapilli and bombs [Donnadieu et al., 2012; 2015; 2016].

A primary objective of modern volcanology is the quantification of the magnitude and the intensity of an eruption in order to characterize both eruption and plume dynamics and better forecast tephra dispersal and sedimentation.

Typically, an early eruption detection and forecast of the tephra plume dispersion can be released within few minutes to a few hours of an eruption, when the scanning radar is operating near the volcanic source, exploiting the radar ability to probe the area affected by the volcanic explosion. Ground-based weather radar systems can also provide data for determining the ash volume, total mass, and height of eruption clouds [Marzano et al., 2012].

In this work, we analyse two Etna paroxysms that occurred in 2013 and 2015 and observed by the X-band MWR (Microwave Weather Radar) and L-band VDR (VOLDORAD-2B; Donnadieu et al., [2016]) radars: i) the explosive activity of 23 November 2013 from the NSEC and lasted for about an hour. This eruption has been widely analysed in previous works, focusing on the eruptive processes and features retrievals [Marzano et al., 2019]; ii) four lava fountain episodes that occurred at Voragine between 3 and 5 December 2015.

Four methodologies have been tested and improved in the calculation of the mass eruption rate using X-band MWR and L-band VDR radar data: TPA (Top Plume Approach), MCA (Mass

Continuity Approach), SFA (Surface Flux Approach) and NSA (approach near the source). These approaches exploit, depending on the case, the X-band MWR scanning capabilities to detect the space-time evolution of the eruption plume and the ability of VDR to detect the exit velocity, from which the incandescent region height HIR is derived applying the Bernoulli equation. We show how the methods based on polarimetric radar in X-band can provide promising results in the comparison between different parametric and numerical models, confirming its potential in operating both individually and in synergy with other sensors and/or methods. The analysis of these case studies indicates that ground-based radars can be exploited to provide a self-consistent monitoring of the time-varying activity of explosive volcanic eruptions. Other case studies should be analysed in order to test and improve the various approaches in estimating eruptive parameters, also by combining radars at different wavelengths (23.8 cm at L band, 3.1 cm at X band and 0.9 cm at Ka band) together with lidar instruments at different wavelengths.

S8.3 - Presentazione orale

Observing volcanic dispersed cloud during the 2016 Etna eruption by dual-wavelength polarized lidar at 355 nm and 532 nm

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Volcanic emissions represent a well-known hazard mainly for aviation safety that can be reduced with real time observations and characterization of eruptive activity [Boselli et al., 2018]. In recent years, lidar system has been widely used to study volcanic aerosol clouds produced by major volcanic eruptions [Pisani et al., 2012]. Lidar techniques are a powerful method for monitoring the dispersion of a volcanic cloud in the atmosphere because of their profiling capability at very high range resolution. Lidar observations can provide plume geometrical properties (i.e., top, bottom, and thickness), aerosol dynamics, and microphysical properties if advanced multi-wavelength Raman Lidar systems are used [Winker, 2003]. Using the depolarization channel, it is also possible to distinguish various shapes of ash particles [Gasteiger et al., 2011; Gobbi et al., 1992; Mereu et al., 2018].
The capability of Lidar systems to detect the finest particles in volcanic plume and reliably estimate the ash concentration mainly depends on instrumental characteristics and the type of explosive activity. For typical ground-based dual-polarized lidars, the evaluation of the aerosol backscattering and depolarization coefficients may be carried out only in those regions where the lidar signal is not extinguished inside the volcanic plume optical thickness.
In this work, we analysed the explosive activity produced in the afternoon of 18 May 2016 at Mt. Etna, in Italy, from the New South East Crater (NSEC). Lidar measurements were performed in Catania, about 30 km from the Etna summit, pointing at a thin volcanic layer, clearly visible and dispersed from the summit craters at the altitude of 3-4 km above sea level. Both the aerosol backscattering and the calibrated particle linear depolarization values profiles at 355 nm and 532 nm of wavelength, respectively, were obtained using different pointing elevation angles 20, 30, 40 and 90 degrees.
This is the first study that combines dual-polarized lidar measurements at Etna volcano. The Maximum-Likelihood (ML) and Multi-Regressive (MR) approaches are implemented in this analysis in order to check the potentiality and differences of both methods, retrieving the mean diameter and concentration retrievals. Our methods show encouraging results and can improve the estimation of volcanic ash concentration in atmosphere.

S8.4 - Presentazione orale

Systematic SO_2 emission patterns prior, during, and after Mt. Etna's paroxysmal phases captured by ultraviolet cameras

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We used two and a half years long SO_2 flux record, obtained using permanent ultraviolet cameras, to characterize changes in degassing dynamics at Mt. Etna volcano from summer 2014 to the end of 2016. Volcanic activity at Mt. Etna was characterized by persistent open-vent degassing periodically interrupted by intense paroxysmal lava fountaining events (in August 2014, December 2015, and May 2016). Results revealed systematic SO_2 emission patterns prior, during, and after Etna's paroxysmal phases, allowing us to identify thresholds between pre- syn- and post- eruptive degassing regimes.
The SO_2 flux typically peaked during a lava fountain: in the 18 May 2016 example, the averaged SO_2 degassing rate was ~158 kg/s, the peak emission was ~260 kg/s, and the total released SO_2 mass was ~1700 tons (in 3h). Paroxysmal explosive activity at NSE crater on 11-15 August 2014 was also associated with intense syn-eruptive SO_2 degassing (at 30-40 kg/s levels on a daily average), and was preceded by onset in degassing activity at the same crater 4 days before. During paroxysmal activity on 3-5 December 2015, the SO_2 fluxes peaked at 54-103 kg/s from VOR crater, and was preceded by a sizable increase from 10 kg/s (end of November) up to 45.5 kg/s, two days before. The May 16-25 2016 paroxysmal activity was characterized by intense degassing ~2 times higher than the 2016 average (~18 kg/s) and preceded by mild but detectable SO_2 flux increases more than one month before its onset.
Taken together, our observations, when combined with independent geophysical (thermal and seismic) evidence, allow us to fully characterize the Etna's degassing dynamics and contribute to our understanding of its shallow plumbing system.

S8.5 - Presentazione orale

Volcanic Cloud monitoring from satellite: the 24-30 December 2018 Etna eruption

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The monitoring of volcanic eruptions has been greatly improved thanks to the technological advances of remote sensing systems. Nowadays, the real time monitoring of volcanic eruptions offers a powerful tool for the risks mitigation on local population and airspace, as also for the analysis of the processes connected with the preparatory phase of an eruption. In particular, the use of geostationary satellites in the thermal infrared spectral range, gives the unique opportunity to follow the entire evolution of a volcanic event during both day and night. Moreover, the higher sensitivity of polar satellite and ground based systems, improves the reliability of the quantitative estimations and gives a comprehensive characterization of the phenomena investigated.
On the morning of 24th December 2018, the explosive activity at the summit craters of Mt. Etna suddenly increased and an eruptive fracture opened at the base of the South East crater. The eruption produces a volcanic cloud that dispersed south-eastwards of the volcano. The explosive regime decreased in the late afternoon of the 24th but a significant SO_2 and ash emission continues until 30th December. The overall event has been monitored, in near real time, by SEVIRI on board the MSG geostationary satellite. The SEVIRI measurements allowed the detection of the volcanic clouds, the estimation of the volcanic cloud height, ash mass, aerosol optical depth and effective radius, SO_2 mass and fluxes. The results indicate a volcanic cloud altitude at about 8 km asl the 24th December and between 4 to 5.5 km for the rest of the period. The volcanic cloud ash and SO^2 were totally collocated with an ash amount generally lower than SO_2, except during the paroxystic phase the 24th December. A total amount of 4 and 2.5 Mt of SO_2 and ash respectively were emitted during the entire eruptive period, and the fluxes reaches peaks of more than 500 kg/s and 200 kg/s for SO_2 and ash respectively. All the products have been compared with the retrievals obtained from ground based and satellite systems. The SEVIRI volcanic cloud altitudes have been compared with the results obtained from the ground based VIS camera operating in Catania while SO_2/ash masses and fluxes time series have been validated with the results carried out from the ground based FLAME network and the satellite measurements collected by the NASA-Terra/Aqua-MODIS and Sentinel5p-TROPOMI polar systems. The analysis indicates good agreement between the satellite and ground based retrievals demonstrating the ability of SEVIRI to characterize the eruptive events in near real time.

S8.6 - Presentazione orale

Tracking volcanic plume dispersion, studying in-plume chemical/microphysical processes and estimating their climatic impacts with new sulphate aerosols retrievals based on thermal infrared observations

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Basing on a unitary theoretical basis for the observation of volcanic secondary sulphate aerosols (SSA) from thermal infrared (TIR) nadir-viewing satellite instruments [Sellitto and Legras, 2016], we have developed new SSA detection and retrieval algorithms for both a high-spectral-resolution sounder, IASI (Infrared Atmospheric Sounding Interferometer) [Sellitto et al., 2017], and a broadband radiometer, SEVIRI (Spinning Enhanced Visible and InfraRed Imager) [Guermazi et al., 2019]. We show that using these new products, in combination with complementary existing products, the atmospheric lifecycle of volcanic sulphur emissions, the in-plume chemical/microphysical evolution processes from gaseous SO_2 emissions to SSA particules and their climatic impacts (both direct and indirect, through the interaction with clouds fields) can be studied and estimated. Two examples of these synergies are presented. First, the detection and tracking of the stratospheric SSA plume from Nabro volcano eruption (summer 2011), using the high-temporal-resolution geostationary SEVIRI observations, is presented [Guermazi et al., 2019]. We show that the buildup of the SSA plume, from SO_2 emissions, can be reconstructed with our new product. Perspectives of coupling these observations with high-altitude clouds detection from SEVIRI are also given, towards the identification of the impact of upper-tropospheric - lower-stratospheric aerosol perturbations from volcanoes on clouds occurrence. Second, a medium-sized tropospheric eruption from Mount Etna volcano (18 March 2012) is studied with a new spectral fitting algorithm using the high-spectral-resolution IASI observations, called AEROIASI-SA. Comparisons with simultaneous and independent SO_2 plume observations and simulations show that AEROIASI-SA correctly identifies the volcanic plume morphology both horizontally and vertically. This method provided, for the first time, crucial information pieces to describe the gaseous-to-particulate volcanic sulphur mass balance (60% of the injected sulphur mass is converted to particulate matter, after ~24 hours) and to estimate the regional shortwave direct radiative forcing (a regional forcing of -0.8 W/m^2 is exerted in the eastern Mediterranean) for moderate volcanic eruptions. Finally, future perspectives on the combined estimation of SO_2 and SSA amounts in volcanic plumes [Sellitto et al., 2019], as well as multi-spectral/instrumental coupling for volcanic plumes observations are discussed.

S8.7 - Presentazione orale

New strategies for chemistry-transport modelling of volcanic plumes: application to the case of Mount Etna eruption in March 18, 2012

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Atmospheric modelling is a useful tool to study and forecast atmospheric composition and the atmospheric evolution of natural and anthropogenic pollutant emissions. It allows to study large scale events such as dust storms or volcanic eruptions, which emit large amounts of plume-confined particulate matter and gases that can be transformed and transported in the atmosphere over hundreds of kilometers. However, to study more precisely these events, different issues have to be addressed. One notable example of these issues is the well-known excessive numerical diffusion in the Eulerian models; this needs to be dealt with in order to avoid excessive plume dispersion, which can cause a misrepresentation of the plume three-dimensional morphology and subsequent geographical extent of its impacts. This work focuses on a particular eruption case of March 2012 from the Mount Etna volcano (Sicily, Italy), which released about 3kT of sulphur dioxide in the atmosphere. This plume has been observed and tracked with satellite instruments for several days. Nevertheless, the numerical simulation of this plume, with CHIMERE atmospheric chemistry-transport model, proved difficult due to the mentioned issue with numerical diffusion. Thus, we have included a new antidiffusive transport scheme in the vertical direction and a new strategy to be able to use directly the vertical wind field provided by the forcing meteorological model, and not a reconstituted wind field as it is the common approach in chemistry-transport models. With these improvements, we were able to more satisfactorily simulate the dispersion of the volcanic plume for this event. In this talk, we examine and quantify the improvement brought by these two new developments into a state-of-the art chemistry-transport model, as well as the effect of an increase in the number of model vertical levels. In addition, sensitivity tests have been performed to evaluate the impact on volcanic plume injection altitude and its initial spreading profile (single altitude emission; FWHM =100m; FWHM=200m).
Tests on altitude plume injection have shown altitude to be the most sensitive parameter, and allowed us to start our developments with a realistic volcanic emissions representation. In opposition, tests on plume vertical profile shape for the injection in the atmospheric column have shown that the simulations are weakly sensitive to this parameter. The use of the new antidiffusive vertical scheme, instead of the classical vertical scheme, has been shown to bring the strongest improvement in our model outputs. To a lesser extent, a more realistic representation of the vertical wind field has also been shown to reduce plume spreading. In summary, we show that these two improvements (better vertical scheme and vertical wind representation) bring an improvement in the representation of the plume which is as strong as the improvement brought by a brutal-force approach (i.e. increasing the number of vertical

levels), but without an additional burden in computational power.
This work is also part of the French funded project DGA TROMPET.

S8.8 - Presentazione orale

High frequency UV camera imagery of Strombolian explosive activity

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Strombolian explosions are intermittent mild eruptions ejecting variable proportions of bombs, ash, and gas. Recent measurements have shown that the SO_2 flux during such explosions starts impulsively (duration, 15 to 30 s) and decays with a minutes-long coda, abd that particles ejections fluctuate at even shorter time-scales. Common UV camera systems measure SO_2 fluxes at about 1 Hz and can potentially lose significant gas variations during explosions. Here we developed a portable UV camera system that can measure SO_2 volcanic flux with a temporal resolution up to about 50 Hz. We tested this new system at Stromboli in May 2019 in tandem with high-speed thermal infrared and visible imagery. Our new, high temporal resolution SO_2 flux measurements provide better understanding of the complex, highly dynamic processes of Strombolian explosive activity.

S8.9 - Poster

Quantitative analyses of volcanic ash from Etna volcano (Italy) and inferences on different eruption styles

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We present preliminary results obtained in the framework of the Ash-RESILIENCE project, funded by MIUR (Italian Government) and working for the period 2018-2020. The main goal of the project is to strengthen the resilience to tephra fallout from explosive volcanic eruptions of the two main metropolitan areas in Italy having active volcanoes within their territory: Catania and Napoli. To this aim, we selected ash samples produced by different eruptive styles at Etna volcano, including the 2002 flank eruption, the 2015 sub-Plinian eruption from the Voragine crater, the 24 December 2018 powerful Strombolian activity from the New South-East Crater, and the following ash emissions from the North-East Crater during January and February 2019. These events are significantly different in terms of intensity and magnitude, well depicted by duration of the activity (lasting from few tens of minutes until several days) and column height (from 4 to 14 km above sea level), as well erupted tephra volume and sedimentation rate spanning different orders of magnitude (10^2-10^6 m^3 and 10-10^5 g/h, respectively).
On these samples, we performed analyses of grain-size, external shape, componentry and composition in order to identify features typical of each style of eruption and associate them to the related mechanism of ash generation. We also evaluated the potential impact on both the environment and the human health of the erupted ash. All the above-mentioned textural and geochemical features are considered essential for the monitoring and forecasting activities of the volcanic ash clouds formation and transport in the atmosphere.
Grain size and particle shape were analyzed to 10 phi (1 micron) using a static particle analyser (Malvern Morphologi 3GSE @DST-University of Florence). Quantitative information on external shape of hundreds of thousands of particles was collected for the same size interval. The analysis highlighted a substantial difference mostly in circularity and solidity between the products of the different eruptive styles. Ash shapes result primarily controlled by vesicularity, with the shape of the products related to higher-intensity activity (sub-Plinian and Strombolian) resulting more irregular respect to that related to lower intensity styles (ash venting). This possibly also reflects the nature and the characteristics of the fragmentation mechanisms involved in the different eruptive dynamics. Another interesting result of this study, contrasting with what previously known for Etna eruptions, is that most of the samples related to the ash emission activity between January and February 2019 (i.e. the lower intensity activity among those studied) are characterized by a large percentage of particles finer than 30 microns, which represents the most hazardous ash fraction for the human health.

S8.10 - Poster

Rock magnetic fingerprint of explosive activity in the Etna ash layers

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A detailed rock-magnetic study was carried out on ash samples produced by different types of Etna explosive activity to test the use of the magnetic properties as discriminating factors among them.
Samples include tephra belonging to:

- Plinian Biancavilla eruption (Y1 tephra; age 16-18 ka) collected in marine core ET97-70 (Jonian Sea);
- sub-Plinian basaltic eruptions of late Holocene age (TV, FS, FL, FG layers + other sub-Plinian deposits) collected in outcrops on the volcano flanks;
- recent explosive activity (1990-2002) including few samples belonging to ash-rich jets and plumes ejected during the October-December 2002 [Andronico et al., 2009].

To better discriminate the magnetic properties of the explosive disintegration of newly erupted magma, the two end members of the juvenile ash, tachylite (microlite-rich) and sideromelane (glassy clasts), were separated from recent ashes (2002 eruption) and from the old FG tephra (122 BC Plinian eruption).
The samples are characterized by coercivity of the remanence (Bcr) to coercivity (Bc) ratios ranging from 2 to 6, defining three main groups according to the position in their Day-Dunlop plot. These groups represent variable magnetic grain sizes corresponding to the old, historical and recent activity. Thermomagnetic curves indicate that Ti-rich titanomagnetites with Curie temperatures <300Â°C dominates the recent ashes and samples collected from the Y1 tephra. On contrary magnetite or Ti-poor titanomagnetite (Tc ~ 540-570°C) occur in most of the late Holocene tephra (TV, FS, FL) suggesting minor or missing Ti-substitution for this class of samples. Only the FG tephra (122 BC) escapes to this figure and highlights the prominent presence of titanomagnetite. The presence of this mineral masks the Verwey transition in low temperature experiments. Concentration related magnetic parameters (magnetic susceptibility, ARM, SIRM) of the samples belonging to the Y1 tephra clearly recognize the stratigraphy of the Unit D (D1a-D2a-D1b-D2b) observed in the fallout deposits of the Biancavilla eruption [Coltelli et al., 2000]. A significant peculiarity in the studied samples is given by the presence of wasp-waisted hysteresis loops in the recent ashes (including the tachylite) whereas only the plinian FG tephra among the old tephra exhibits similar loops that can depend on two magnetic components with contrasting grain sizes or coercivities. The latter is supported by the FORC diagrams where the Bc distribution spreads up to 0.2T, pointing out the presence of a harder magnetic fraction. However, Mossbauer data carried out at low (20K) and room temperature (300K) do not show the presence of antiferromagnetic minerals. The scattering within the Day plot of the samples belonging to the recent activity could be the result of the intense fragmentation that usually characterizes the most explosive volcanic explosions. The magnetic signature of the fragmentation could be present in the magnetic grain size, but the magnetic properties may be

also affected by low temperature modification such as oxidation or exsolution due to the breakdown of the solid solution between ulvospinel (Fe_2TiO_4) and magnetite (Fe_3O_4). The differences in the magnetic properties of the tachylite and sideromelane represent a discriminant factor distinguishing the products of Hawaiian fountains and the Strombolian activity with respect to the explosive activity related to ash-jets and plume.

S8.11 - Poster

SO_2 flux at Stromboli over the 2019

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Stromboli is characterised by persistent eruptive activity consisting on rhythmic and moderate strombolian explosions. This eruptive style together with the easy access of the volcano, has made Stromboli a unique touristic attraction and an open-laboratory to develop and study active volcanoes. Nevertheless, the ordinary explosive activity is randomly interrupted by explosions of higher intensity 'major' and paroxysms, with dramatic effect on the exposure and vulnerability of people and scientist in the island. Over the 2019, the ordinary strombolian activity displayed an increase in terms of frequency and intensity of explosions, eventually followed by a major explosion in June and two paroxysmsin July and August. Degassing regime reflected in the SO2 emission rate, showed variation coherent with the eruptive activity with stages of increase in spring and sustained values between July and August. SO2 flux reverse gradually this trend in late September. Here we'll discuss the potential correlation between SO2-gas and the eruptive activity and the balance between erupted and degassed magma inverted from the observed SO2 flux.

S8.12 - Poster

S11. VOLCANIC AND HYDROTHERMAL SYSTEMS: FROM GEOCHEMICAL PROCESSES TO MONITORING ACTIVITIES

Conveners:
Cinzia Federico (INGV-PA), Marcello Liotta (INGV-PA),
Marco Liuzzo (INGV-PA), Orlando Vaselli (UniFI)

Chemical anomalies in the gas phase released from the Santa Venera al Pozzo thermal spring (Mt. Etna, Sicily, Italy): possible influence from local tectonic activity

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The site of Santa Venera al Pozzo, on the lower east flank of Mt. Etna volcano, near the town of Acireale, is known for its slightly thermalized, mineral-rich water springs since antiquity. The site was interpreted by scholars as a Roman "statio", mainly composed of a thermal bath with different pools and some other Greek-Roman buildings. The study area is affected by several tectonic faults; actually, some archeological ruins are affected by remarkable fractures probably related to the AD 251 earthquake, suggesting the occurrence of a capable fault zone through the area. Recent studies have shown that significant soil CO_2 emissions occur both from the major faults and diffusely around the main thermal water springs, thus suggesting a fault-driven migration of geothermal fluids. In order to study possible influences of strain release on the output or on the chemistry of the emitted fluids, we set-up a monitoring system that measures in continuum water temperature and the chemical composition of the free gas released from water in a drilling made near the main water spring. Water temperature was measured using a Tynitag Plus2 sensor/datalogger, setting an acquisition frequency every 15 min.
The gases emitted are a mix of air, methane, carbon dioxide, ethane and sometimes hydrogen sulfide. The chemical and isotopic composition of the emitted fluids suggest that these are fluids that do not have a volcanic origin. Methane, which is the most abundant gaseous species, has a thermogenic origin, carbon dioxide has an organic origin while the presence of hydrogen sulfide is related to the increase of methane concentrations.
Variations in the chemical composition were realized with a CMS (cromatography monitoring station) that allows the analysis of natural gases (every 30') with high sensitivity and accuracy. During the acquisition period variations in the chemical composition were observed on some occasions and in particular before, during and after the earthquake of 12/26/2018 related to a kinematic tectonic stress that produced a greater permeability and a consequent greater release of fluids. In particular, before the earthquake the methane displayed a sharp increase, while on the occasion of the seismic event a doubling of concentrations was observed. Hydrogen sulfide is present before and shortly after the seismic event is well correlated with methane concentrations.
It can be hypothesized that both species are related to a hydrothermal system and the measured concentrations are modulated by the emitted gas flow. Hydrogen sulphide generally, due to its high solubility in water, is removed from the interaction by a superficial aquifer present in the area of the thermal spring while its presence is detected when the gas flow increase and it is only partially dissolved in water.
The recorded water temperature showed a long-term seasonal variation, mostly evident during the summer period, and shorter daily variations. However, two anomalous changes were observed during the occurrence of two earthquakes on October 6th, 2018 and on December 26th, 2018. Both variations consisted of sudden drops in the temperature values, followed by a

slower recovery (9 and 7 hour-long, respectively) to previous values.
Both anomalies seem well correlated with local seismic events above mentioned, as the first one on October 6th, 2018 with a Mw 4.6 that struck the town of Ragalna (SW slope of Mt. Etna), with epicenter located 18.5 km west of the monitoring station, and the second one which occurred on December 26th, 2018 with a Mw 4.9 earthquake along the Fiandaca fault, with epicenter 7.5 km NW of the monitoring station. This suggests a close connection between release of tectonic stress and permeability changes that may have caused a water table drop that in turn has promoted a greater emission of cold gas.

S11.1 - Presentazione orale

Clues on the potential role of microbial communities in mitigating greenhouse gas emissions from hydrothermal systems

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Volcanic and hydrothermal areas are sites of intense diffuse soil degassing, largely contributing to natural emissions of greenhouse gases (GHGs) to the atmosphere. While deep magmatic and hydrothermal sources sustain the rise of CO_2- and CH_4-rich fluids towards the surface, the effective fraction of deep-sourced gases able to escape to the atmosphere through diffuse soil degassing is largely affected by secondary processes occurring at relatively shallow depths. Although posing challenges to life, hydrothermalized soils still harbor a variety of microbes (i.e. extremophiles) able to take advantage of the harsh conditions offered by solfataric fields. For instance, the occurrence of methanotrophic activity in soils from hydrothermal areas, documented by several authors, could virtually control and limit the emission of GHGs from volcanic and hydrothermal systems. In order to evaluate the impact of shallow biogeochemical processes on diffuse gas emissions, chemical and carbon (in CO_2 and CH_4) isotopic compositions of interstitial soil gases, as well as diffuse CO_2 fluxes, from three hydrothermal systems in Italy (i. Solfatara Crater, Campi Flegrei; ii. Monterotondo Marittimo, Larderello geothermal field; iii. Baia di Levante, Vulcano Island) were investigated. Despite being characterized by a large supply of hydrothermal fluids, as indicated by soil CO_2 fluxes up to 2400, 1920 and 346 g m-2 day-1, respectively, $^{13}CO_2$ enrichments were recognized in interstitial soil gases with respect to fumarolic fluids, suggesting the occurrence of autotrophic CO_2 fixation processes in the soil system. On the other hand, soil gases were enriched in $^{13}CH_4$ and characterized by higher CO_2/CH_4 ratios with respect to those recorded in fumarolic discharges, pointing to the occurrence of CH_4 consumption by methanotrophic activity, as supported by isotope fractionation modeling. The geochemical evidences confirmed the key role that methanotrophs play in regulating the release of GHGs from volcanic and hydrothermal environments.

S11.2 - Presentazione orale

Evidence of a new gas input of deep origin at Vulcano (Aeolian Islands) observed in the shallow groundwater and soil gas emissions

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Hydrothermal systems develop in a variety of geological settings where heat flow and fluid circulation warm the rocks hosting the water. The resulting surface manifestations, e.g. fumaroles or hot springs, are often the unique accessible expressions of such systems. They vary widely in their appearance and reflect the type of hydrothermal reservoir from which the discharged fluids originate. In volcanic zones, the gases released from magma (e.g. H_2O, CO_2, sulfur and other gas components) interact with water of meteoric origin during ascent toward the earth's surface and the hydrothermal systems develop at various depth in the volcanic edifices. The island of Vulcano is an excellent natural laboratory where the interaction between magmatic gases and water of various origins can be investigated in a volcanic-hydrothermal system. In particular, this study focuses on the gas-water interaction processes occurring in the shallow groundwater of the Vulcano Porto because of the availability of several water wells regularly accessible in the targeted area. Furthermore, residential and tourist facilities there expose people to gas hazards due to the active volcanic system of La Fossa cone. The risk mitigation and management actions from the Civil Protection Agency encompass volcano surveillance programs from INGV, which accomplishes soil gas emissions and groundwater monitoring.

This study focuses on the chemical-physical parameters of the groundwater, the total dissolved inorganic carbon (TDIC), the amount and the isotopic composition of the CO_2 dissolved in groundwater. The partial pressure and the carbon isotope composition of CO_2 dissolved in groundwater were computed from the TDIC, based on the equilibrium model. These data have been compared with the measurement of the same parameters in the gases dissolved in waters, which were collected through a passive sampling technique. The dissolved gas phase has been investigated also for chemistry and helium isotope ratio. Finally, the data from shallow groundwater have been compared with the CO_2 flux and the carbon isotope composition of CO_2 emitted by soils of the Vulcano Porto.

The surveys for the shallow groundwater have been performed in 2015 (May) and 2018 (September and November). The sampling grid of groundwater consists of seventeen wells distributed in the Vulcano Porto area. The data collected in the field indicate that water temperature ranges from 20.0 °C to 58.8 °C, pH from 6.29 to 7.95 and conductivity from 0.12 m^S/cm to 34.10 m^S/cm. During the same surveys, the coupled approach of CO_2 flux and the carbon isotope composition of CO_2 from the soils has been applied over a sampling grid of fifty-two sampling points. The data analysis revealed that the large part of CO_2 has biogenic origin in the shallow levels of the soils ($\delta^{13}C_{(CO2)}$ < - 14.0 ‰ vs PDB), while two anomalous zones (CO_2 flux > 117 g m^{-2} d^{-1}) of Palizzi and Faraglione are fed by deep-origin gases ($\delta^{13}C_{(CO2)}$ > - 3.0 ‰ vs PDB).

The spatial analysis of the CO_2 flux from the soils indicates that the location of the anomalous degassing zones coincides with the area of the high partial pressure of dissolved CO_2 in

groundwater. Furthermore, the monitoring of chemical-physical parameters of the groundwater indicates an increased input of gases from deep origin which produced the changes observed during September 2018 in the shallow hydrothermal system and the soil gas emissions. These changes agreed with the remarkable chemical and isotopic variations observed in the crater fumarolic field (see Bollettino Vulcano September 2018 and Bollettino Vulcano November 2018 - https://www.pa.ingv.it/index.php/category/bollettini/).
The application of isotope and chemical-physical parameters of groundwater and those of soils gas emissions offers a unique opportunity to model in detail the circulation of fluids in a volcanic-hydrothermal system and results an effective tool for volcano monitoring.

Preliminary results of carbon degassing in the tectonically active areas of Balkan Peninsula

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The deeply derived CO_2 from tectonically active areas is contributing in a significant proportion, still un-quantified in detail, to CO_2 Earth degassing. Several studies highlighted how in these tectonically active areas most of the CO_2 is dissolved in the groundwaters circulating in the large regional aquifers hosted by the permeable formations of the active orogens. Quantifying the amount of deep CO_2 dissolved into groundwater can represent a powerful tool for regional investigations, because springs are representative of their catchment area that can extend from tens to hundreds of square kilometers.

In the framework of a Deep Carbon Observatory supported project, we investigated for the first time, the geogenic carbon emission from the Balkan Peninsula (southeastern Europe). This area is known for its high carbon Earth degassing (both CO_2 and CH_4), but lacks the necessary data for quantification and for determining the origin of carbon (especially for what regards the isotopic composition of dissolved carbon). We investigated thermal manifestations (thermal springs and drillings), CO_2 emission (including dry and wet moffetas), thermal wells containing CH_4 and karst springs from tectonically active areas.

During the field investigation, we visited Romania (Mangalia and Tyulenevo coastal area (Romania and Bulgaria), Apuseni Mountains, Ciuc Basin and Herculane Graben), Slovenia, Central Serbia, Macedonia and Croatia visiting and collecting more than 350 sites. Water samples were collected for water chemistry, water stable isotopes, carbon-13 from TDIC, dissolved H2S, dissolved gas composition, carbon-13 from CO_2 and CH_4 from dissolved gases, and for dissolved noble gases (He, Ne, Ar). For those sites were also free gas was present, the team collected free gas samples for compositional, isotopic and noble gas analyses.

The availability of this data is the first attempt in quantifying the carbon flux with real data from this tectonically active area.

S11.4 - Presentazione orale

Geochemical study of high temperature fumaroles and non-plume degassing in Mt Etna's summit area

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A campaign of geochemical measures was carried out in the summit area of Mt Etna during the summer of 2019 in order to study both high- and low-temperature fumaroles and the geometry of diffuse degassing areas there present. The aims were: i) to improve our knowledge about the geochemical characteristics of non-plume degassing; ii) to define the extension of the shallow hydrothermal system around the summit craters of the volcano; iii) to assess all possible interactions between the shallow hydrothermal system and deeper melt through which the gas flux takes place; iv) to monitor the temporal evolution of the gas emissions, trying to discriminate between shallow-related variations and those related to deeper contributions.
The study was conducted through: i) gas sampling of high temperature fumaroles within a fracture on North-East Crater (NEC) and along the crater rim of Voragine (VOR); ii) measurements of soil CO_2 flux and soil heat flux on the summit area, particularly along the rims of Central Crater (Bocca Nuova [BN] and VOR) and NEC, and also along the flanks of the summit cone; iii) installation of a permanent station for continuous monitoring of the concentrations of CO_2 and H_2 in a steaming fumarole (T° of about 90 °C) inside the uppermost crater formed during the 2002 flank eruption, on the upper north side of the volcano. This site has continued producing gaseous emissions even after the end of the 2002 eruption and the gas emission has been found to be directly linked to the degassing of the summit area.
This work shows the preliminary data acquired during the geochemical survey, summarised as follows: i) high temperature fumaroles show an average C/S ratio of 6.3, but this ratio changes from one crater to another; ii) the diffuse CO_2 flux combined with soil heat flux allowed identifying areas with a greater component from direct magmatic degassing. These areas are mostly located on the rims of the craters, but some isolated anomalous points were found in places where recent eruptive products have buried old volcano-tectonic fractures or old fumaroles; iii) the temporal evolution of the gases from the 2002 crater shows a strong positive H_2 peak and a negative CO_2 peak at the onset of Strombolian activity at the NEC (on the night of 8-9 September 2019). Several cyclic variations in the composition of gaseous species were also observed, with daily period, as well as changes in the CO_2/H_2 ratio that will deserve further studies in the follow-up of this research.

S11.5 - Presentazione orale

Carbon Dioxide Diffuse Emission from the Soil at Cava dei Selci (Colli Albani, Rome): two decades of observations and preliminary gas hazard assessment

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Carbon dioxide flux from the soil has been regularly monitored in the area of Cava dei Selci (Colli Albani) with the main aim of investigating if the surface phenomena could provide information about the processes occurring at depth. Cava dei Selci, located on the north-western flank of Colli Albani quiescent volcano, is characterized by a permanent gas emission as consequence of the removal of the low permeability surface cover made of lahar deposits from Albano crater lake. Cava dei Selci is a densely inhabited zone about 20 km from the center of Rome, where lethal accidents by gas inhalation have occurred to a human and to dozens of animals including cows and sheep.
Surveyed area includes a fixed grid of 120 points, regularly distributed over an area of about 5000 m^2, where soil CO_2 flux was measured 51 times from May 2000 to October 2019. In addition, we analysed the data of a large survey (performed in March 2011), including the area of the regular grid and the surroundings for a total of more than 1100 measurements, and the temporal series of an automatic permanent station that continuously measured the CO_2 flux and some environmental parameters that can potentially influence the CO_2 diffuse degassing (2003-2008 period).
We considered, with statistical and geostatistical procedures, the features of the acquired signals, evaluating the spatial and temporal variations of the CO_2 degassing process in relation to tectonics, seismicity, local soil properties (e.g., hydraulic conductivity) and meteorological parameters (in particular rainfall).
The series of the CO_2 output, obtained through the sequential Gaussian simulation approach, is highly fluctuating, with a maximum emission of 26.1 t d^{-1} in January 2006 and a minimum value of 5.6 t d^{-1} in December 2003; the estimated mean CO_2 is 12 t d^{-1} (1σ=4.8 t d^{-1}). All the maps show typically a highly emissive area in the internal sector of the investigated grid, with elongation NW-SE.
We argue that the local NW-SE elongated eruptive fissure, starting from the Albano lake and crossing the target area, acts as preferential pathway for the migration of the deep gas to the surface.
Some periods characterized by high emission are clearly linked to seismic events of the Colli Albani area, as the highest emission of January 2006, but this correspondence does not always seem fair. On the contrary, surveys characterized by low emission are typically linked to rainy periods, when probably deep rising gases are dissolved inside local shallower aquifers refilled by "fresh" waters of the rains.
We used the dense dataset of CO_2 output and meteorological measurements collected at Cava dei Selci to model air CO_2 dispersion in the neighbourings of the natural emission, including the densely inhabited area. To this purpose, we applied the DISGAS (DISpersion of GAS) numerical

code coupled with the Diagnostic Wind Model (DWM). CO_2 concentrations in air were determined for different CO_2 emission rates: the mean, the minimum, and the maximum flux, as well as the global flux obtained by the large survey of March 2011 (about 40 t d-1 of CO_2), under different wind conditions.

Maximum CO_2 concentrations in air (about 1000 ppm above the local background CO_2) are predicted inside the sector of the gridded area, in correspondence with the maximum CO_2 emission from the soil, as well as in some spots located in the village of Cava dei Selci.

Even considering the maximum CO_2 emission rate measured in the last twenty years and the most unfavourable atmospheric conditions (i.e. low wind and atmospheric stability), results of the simulations indicate that predicted concentrations are below the "hazardous" threshold of 5000 ppm of CO_2. In any case, the actual gas hazard could increase for the presence of other not included sources of gas, for processes of gas accumulation inside basements or morphologically depressed sites or if the natural CO_2 flow rate increase to 4/5 times the current one, for example as consequence of seismic events.

S11.6 - Presentazione orale

Gas-water-rock interaction in the summit fumarolic system at Vulcano crater by continuous monitoring of fumarolic fluids

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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. In fact, the chemical and isotopic composition of fluids, and their emission range from the earth's crust, are strongly dependent on local phenomena (presence of magmatic intrusions, crustal discontinuities etc.). The emissions of the diffused soil gases, fumaroles and plume gases are very common on our planet and often they occur through spectacular phenomena. The geochemical monitoring of high temperature fumaroles is currently performed using the Giggenbach method. This method [Giggenbach and Gougel, 1975; Sortino et al., 2006] allows the sampling of the main and minor gas components, and their traces, in high temperature fluids, but requires the presence of an operator on field and consequently the sampling frequency is variable. Fast variations in chemical composition can be attributed to volcanic activity but not enough is known about the influence of environmental factors (rains, tides, temperature). In May 2019, a CMS (Cromatography Monitoring System) was installed on the Vulcano crater with the aim of verifying the possibility of installing a chromatographic system with sensitivity and accuracy typical of laboratory analysis. Aims of this approach was to create a system of continuous monitoring of the fumarolic fluids (from the F0 fumarole, located on the rim of the Vulcano crater) that acquire data every 5 minutes in order to have timely and precise information on the variations of the chemistry in high temperature fluid. During the short acquisition period, variations in the chemical composition were observed, not related to atmospheric pressure but to the amount of rainfall. H_2S concentrations display decreases during the single rain event probably due to the rapid dissolution for the high solubility of this gas in water. A general system has also been hypothesized in which the rains interfere considerably with the concentration of the single species emitted. Rainwater infiltration occurs mainly through the bottom crater and produces a temporary interaction with the fumarole feeding system in the summit area of the volcano, resulting in a partial removal of the soluble gases and consequently produces a decrease in the quantity of gas emitted. This hypothesis was supported since, although the instrument worked perfectly, the quantity of dry gases and in particular of CO_2 had decreased considerably. Although the acquisition time was short these measures allowed to display that the rock-gas-water interaction processes never highlighted with discontinuous measures. A longer installation could allow us to verify what has been observed and better study the hypothesized processes.

S11.7 - Presentazione orale

Assessment of the geothermal potential along the northern margin of the Hyblean plateau (Sicily, Italy) from groundwater geochemistry

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We describe the geochemical characteristics of ground water samples collected in 23 water wells located on the northern margin of the Hyblean plateau (East Sicily). This area, mostly made of highly permeable carbonate rocks, is rich in hydrothermal groundwaters at low temperature (T<50°C at outlet) and it is also an active sismogenetic zone, being it crossed by several ENE-WSW-directed tectonic structures that drove magma to the surface during Upper Pliocene and Pleistocene. Our samples show a surface temperature lower than 40°C and chemical features that suggest complex mixing between rainwater, CO_2-rich groundwater, steam-heated groundwater and geothermal waters. Some samples show evidence of strong interaction with CO_2, whose origin is from mantle degassing, as indicated by carbon isotopes. Other samples indicate interaction with condensed geothermal brines. Geothermometric estimates, mostly based on the quartz geothermometer, suggest maximum reservoir temperature between 100 and 120 °C.

S11.8 - Poster

Exploring geothermal systems: application and limits of solute geothermometers

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Volcanic-hydrothermal systems are characterized by multiphase fluid flow processes responsible of complex chemical reactions and heat transfer from magma. Solute geothermometers represent one of the major tools for the exploration of the subsurface geothermal resource as well as to estimate deep water temperatures and rock-water equilibrium at deep conditions. Under equilibrium conditions, water-rock interaction implies the simultaneous existence of dissolution, precipitation and exchange processes under given temperature, pressure and salinity conditions. If the equilibrium is attained, geo-thermometers can provide a realistic evaluation of the temperature. In this work we present details of methods and some application examples of the Na-K-Mg thermal diagram of Giggenbach [1988]. Its use is widespread around the world for the innovative approach to study geothermal systems. The approach proposed by Giggenbach [1988] included several constraints for its successful application. Thermal-water composition is used to classify groups of water and their origin, and to prove if water-rock equilibrium (i.e the equilibrium of a thermodynamically stable mineral phase with water) is attained [Giggenbach, 1981]. Alternatively, if the equilibrium is only partially attained or other processes are involved (e.g. seawater, cold brines, connate waters), interpretation of temperatures obtained from geothermometry equations requires to be critically evaluated in order to avoid over-interpretation of the analytical results. The obtained findings highlight the need of cautiousness when using the diagram to estimate temperature of hydrothermal systems.

S11.9 - Poster

Geochemical Characterization of Trace Elements in Thermomineral Waters of Greece

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Trace elements have a fundamental role in natural and anthropogenic systems. In waters, they present a great variability of concentrations that mostly depends on the degree of gas-water-rock interactions and geochemical conditions such as pH, temperature, redox and/or exchange reactions, etc. Even though, they are present in very low contents in host-rocks, elevated concentrations in ground or surface waters may have a hazardous impact on human and animal health and thus, it is important to both quantify and try to understand their behaviour in natural systems.
Here we present the results of about 300 cold and thermal mineral waters collected along the entire Hellenic territory. Physicochemical parameters (temperature, pH, electrical conductivity and Eh) were measured in situ, whilst samples were analysed by Ionic Chromatography (IC) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for their major and trace elements' content. The great variability in hydrogeological settings justifies the wide range of temperatures (6.5 - 98°C) and pH (1.96 - 11.98). Total Dissolved Solids (TDS) values also covered a wide range, from 0.06 to 43 g/L. Based on the combination of pH, T and TDS, samples were subdivided into 5 classes: i) thermal waters; ii) thermal waters affected by sea water contamination; iii) cold CO_2-rich waters; iv) hyperalkaline waters; and v) acidic waters.
The great variability in chemical composition of the sampled waters is reflected in the large range of trace element contents (four to five orders of magnitude). Thermal waters affected by seawater contamination show the strongest enrichments in Li (up to 17,600 μg/L), B (up to 38,200 μg/L), Sr (up to 80,000 μg/L) and Rb (up to 9230 μg/L), mostly deriving from water-rock interaction. Cold CO_2-rich waters display elevated concentrations of Mn (up to 3970 μg/L), Ni (up to 111 μg/L) and Fe (up to 218,000 μg/L), whilst at the water outflow an extensive precipitation of iron oxi-hydroxides is observed. Hyperalkaline waters are generally strongly depleted in trace elements due to the precipitation of secondary minerals, however they are enriched in Al (up to 421 μg/L). Aluminium becomes soluble at extreme pH conditions and therefore also acidic waters present enhanced concentrations (up to 100,000 μg/L). Acidic waters show also enrichments in Fe (up to 58,400 μg/L), Mn (up to 15,600 μg/L) and Ni (up to 101 μg/L).
In some cases, the maximum contaminant levels (MCLs) fixed by the Directive 98/83/EC for drinking water (and subsequent updates), are strongly exceeded in the under investigation waters. Such elevated concentrations of harmful elements may create hazards to human health either via direct consumption of cold mineral waters or through mixing of highly mineralized waters - even in small proportions - with shallow groundwater. For instance, As (MCL 10 μg/L) in the sampled waters reaches concentrations up to 1820 μg/L that derive from high temperature water-rock interaction within the hydrothermal circuit.

S11.10 - Poster

Geochemistry of fluids and CO_2 output in the southern Apennine (Italy): preliminary results for cold and thermal waters

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Although central to our understanding of planetary evolution over geological time, past and present natural CO_2 fluxes are poorly quantified [Berner e Lasaga, 1989]. This limited knowledge is caused by CO_2 being emitted from the Earth's interior in different geodynamical contexts, in different modes and at different rates.
Mantle degassing and CO_2 emissions from the Earth's mainly occur in volcanic regions, in young oceanic lithosphere setting (e.g., Foley and Fisher, [2018] and references therein), but an active and robust CO_2 degassing also occurs in seismically/tectonically active regions [e.g., Chiodini et al., 1999 and 2004; Caracausi and Sulli, 2018], that are punctuated by CO_2-rich manifestations, including cold gas vents, degassing soils and CO_2-rich springs [Barnes, 1978]. These manifestations are clear hints for anomalous transport of deep CO_2 toward the surface through faults systems that are weakness zones in the crust because of the enhanced permeability. Regional aquifers, in particular, can dissolve large amounts of CO_2 providing geochemical evidences for deep degassing processes at regional scale [Chiodini et al., 2000].
Studying regional aquifers and their main springs is thus key to establishing regional CO_2 budgets [e.g., Chiodini et al., 2000; Burton et al., 2013 and references therein]. Unfortunately, relatively few studies have targeted CO_2 degassing from worldwide non-volcanic areas. Furthermore, a link was identified between CO_2 output and seismicity [Chiodini et al., 2004], so that the study of CO_2 degassing in active tectonic region can furnish new tool to investigate the seismogenetic processes.
Here we present preliminary results of a geochemical study on CO_2 degassing in the southern Italy (Basilicata-Calabria area). The investigated area is a tectonically active region, where historical and recent earthquakes have been recorded (magnitude up to 5.2) [Presti et al. 2013 and reference therein].
We collected and analysed 45 samples, both cold and thermal groundwaters, with the aim of defining the origin of the dissolved gases, quantifying the CO_2 output at regional scale and understanding the origin for regional thermalism. In this contest, helium has been used as the key tracer for recognizing the contributions of crustal and mantle components and the associated heat [Mamyrin and Tolstikhin, 1984]. The collected water have been divided in 3 groups on the basis of their major element chemistry: Ca(Mg)-HCO_3, Mg(Ca)-HCO_3 and Ca(Na)-SO_4. The δ^8O and δD isotopic signature of groundwaters falls close the Eastern Mediterranean Meteoric Water Line (EMMWL, Gat and Carmi, [1970]; Rindsberger et al., [1983]) indicating its meteoric origin. Helium and neon isotopes indicate our samples fall in the field of ASW (Air

Saturated Water), with the exception of the thermal waters. The latter identify mixing between atmospheric and a radiogenic end member, but these also exhibit trace mantle contributions This could be related to the rise of fluids through the faults present in the area (e.g *Pollino fault*, *Sibari fault*). Coupling Total Dissolved Inorganic Carbon (TDIC) and $\delta^{13}C$ compositions we identified 2 groups of waters (i) infiltrating waters, with low $\delta^{13}C_{TDIC}$, and (ii) a group of samples with more positives $\delta^{13}C_{TDIC}$ and higher TDIC, indicative of outgassing of deeply sourced $CO_{2.}$ By applying the carbon mass balance approach proposed by Chiodini et al. and considering the hydrogeological parameters of the studied springs, a first estimate of the deep CO_2 flux has been attempted. In addition, the final objective of the study is also to make an estimate of the regional CO_2 budget, characterise the geodynamic setting and identify the possible relationships with seismicity that could better explain the role of fluids in seismic events.

S11.11 - Poster

Monticchio lakes

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The crater lakes are a natural hazard for the population living near them because they can generate liminic explosions, like as the disaster of Nyos lake (Cameroon 1986), in which 1476 people and thousands of animals died. Crater lakes are able to store magmatic and hydrothermal gases and solubilising them into the water. An overpressure of the dissolved gases can generate a limnic eruption. Italy is characterised by an intense volcanic and seismic activity. Evidences of this past volcanism are the numerous crater lakes in Lazio and Campania. The most famous are Bolsena lakes, Vico, Bracciano, Monticchio lakes, Mezzano, Martignano, Albano, Nemi, Averno. The Monticchio lakes (Piccolo Lake (LPM) and the Grande Lake (LGM)) have formed in two maars localized in the Mt Vulture (Basilicata), a Quaternary, not active volcano, characterized by anomalous high flows of CO_2 emitted by soils. They are separated by an isthmus of about 200 m. The two lakes have different morphological characteristics: LPM has an area of 160.000 m^2, a steep floor and a maximum depth of 38 m. The LGM has an area of 380.000 m^2, and the maximum depth of 36 m in its northern part. The two lakes solubilise high level of gases. The high CO_2 tenors and the high values of He^3/He^4 isotope ratios are ascribable to a deep magmatic degassing.
In this study we investigate the physical-chemical parameters (electrical conductivity, temperature, Eh and pH) and the chemical composition of major and traces elements along two bathymetric profiles. Monticchio Lakes were sampled in June 2018. The samples, taken in different depth, are 20 in total: ten from LMP and ten from LMG. The physical-chemical parameters were measured at different depth by a multiparametric probe. The major and trace elements are analyzed in the laboratory of INGV (Istituto Nazionale di Geofisica e Vulcanologia) in Palermo.
The physical-chemical parameters show the different layers in Monticchio Lakes. In both lakes the range of temperature is 5.6 °C and 20 °C. Lakes show different range of pH being between 6.5 and 8.6 in LMP and between 6 and 7.6 in LMG. The range of Eh is between -152 and 258 mV and between -144 mV and 141 mV. in LMG and LMP respectively, being the negative values in depth due to anoxia phenomenon. The two lakes have a similar thermocline layer, around -6m. In summer, the both lakes are mostly layer because the sun energy warming the surface layer of lake. This phenomenon makes the hot layer upper the cold layer. In LMG, the range of electrical conductivity varies little with depth (411 - 526 microS/cm). Instead, in LMP, the range of electrical conductivity is greater ranging from 339 to 1456 microS/cm. For this reason, the halocline is different in both lakes, In LMP, the salt concentration increases with the depth.
LMP and LMG waters in Langelier-Ludwing classificative plot have both bicarbonate earth-alkaline compositions. On the contrary, traces elements (Li, Be, B, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Cd, Sn, Sb, Te, Cs, Ba, Pb, Bi and U) have different characteristics. In LMP, B, V, Mn, Zn, Sr, Cr, Fe and Mn show higher concentrations respect the other trace elements. Instead in LMG, the more concentrated trace elements are Li, Ti, Cs, Rb, Ba, Fe and Mn. In Both lakes' Fe and Mn increase with the depth.

S11.12 - Poster

Thermomineral waters of Greece: geochemical characterization

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Many geothermal areas of Greece are located in regions affected by Miocene or Quaternary volcanism and in continental basins characterised by elevated heat flow. Moreover, the majority of them is found along the coast as well as in islands of the Aegean Sea and thus, thermal water is often brackish to saline due to marine intrusion into costal aquifer.
In the present study, almost 300 thermal and cold mineral water samples were collected along the Hellenic territory with their physicochemical parameters (temperature, pH, electrical conductivity and Eh) and the amount of bicarbonates (titration with 0.1N HCl) being determined in situ. Additionally, gases, found either in free or dissolved phase, were sampled. Both water and gas samples were analysed at the INGV-Pa laboratories for major ions (Ion Chromatography), silica (Inductively Coupled Plasma - Optical Emission Spectrometry), chemical composition of free and dissolved gases (Gas Chromatography) water isotopes (O and H) and carbon and helium isotopes of free and dissolved gases (Mass Spectrometry).
The temperature of the investigated waters ranges from 6.5 to 98°C, pH from 1.96 to 11.98, whilst Total Dissolved Solids (TDS) from 0.06 to 43 g/L. Based on the temperature parameter, waters can be divided into four groups: i) cold (< 23 °C), ii) warm (23 - 40 °C), iii) thermal (40 - 75 °C) and iv) hyperthermal (> 75 °C). In terms of pH, most results vary from 5.5 to 8; few springs show either very low pH (< 4) suggesting interaction with H_2S-rich gases or very high pH values (> 10) proposing serpentinization processes.
Regarding TDS concentrations, collected waters can be subdivided into low salinity (up to 1.5 g/L), brackish (up to 20 g/L) and saline (up to 43 g/L). The medium - high salinities can be justified by mixing with sea water and/or strong water-rock interaction processes. Isotope composition of O and H ranges from -12.7 to +2.7 ‰ SMOW and from -91 to +12 ‰ SMOW respectively and is generally comprised between the Global Meteoric Water Line and the East Mediterranean Meteoric Water Line. Only few water samples show a positive shift for $\delta^{18}O$ possibly related to high temperature water-rock interaction processes.
Carbon dioxide (18 - 997,000 µmol/mol) or N2 (1100 - 989,000 µmol/mol) or CH_4 (< 0.5 - 913,000 µmol/mol) are the prevailing gas species found in the studied sites. The $\delta^{13}C_{CO2}$ values ranged from -20.1 to +8.5 ‰, whilst the isotope ratio of He from 0.21 to 6.71 R/RA.

S11.13 - Poster

A web app for processing volcanic gas data from Multi-GAS instruments

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Here we report on an interactive web app developed with the Shiny package of the R programming language that allows to process volcanic gas data acquired with sensor-based instruments (aka Multi-GAS). Users can access to the web app via internet connection (no installation required) upon registration with a username and a password and upload their own single or multiple data files as plain text tables (e.g. CSV format). The processing tools allow to easily calculate gas molar ratios and to perform automatic batch analysis on large dataset. Given that the Multi-GAS instrument is playing an increasingly important role in the geochemical monitoring of active volcanoes worldwide, we are confident that this web app may represent a very useful tool available for the scientific community and a potential future on line platform for sharing knowledge on the processing of such data.

S11.14 - Poster

Groundwater flow characterization and reconstruction of the hydrothermal system of Ischia as a tool for volcanic risk mitigation

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The volcanic system of Ischia is characterized by an intense hydrothermal activity, documented since the early 16th century by the study of Iasolino [1588], which represents the first systematic analysis of the thermal springs of the island for therapeutic purposes. Later studies partially contributed to the enhancement of knowledge on the volcanic, hydrogeological and hydrothermal features of the island, highlighting the strong interaction between hydrothermal flowpaths and volcano-tectonic processes. The reconstruction of the hydrothermal system becomes, therefore, a fundamental element for territorial planning, not only in terms of management of the huge water and geothermal resource, but also and above all in a perspective of prevention and mitigation of volcanic risk. Thermal springs, fumaroles and clay deposits due to the hydrothermal alteration of volcanic products testifies for the existence of an active deep hydrothermal system. However at Ischia the geochemical characterization of fluids and groundwater, performed through sampling and analysis of a discrete number of scattered springs, wells and fumaroles, has been used for the definition of the origin and structure of hydrothermal systems as a whole, as the hydrogeological information is incomplete. Moreover, volcanic hydrothermal systems, such as that characterizes the island of Ischia, are particularly difficult to analyze and outline, as the groundwater resources are the result of an articulated and dynamic interaction among meteoric water, sea water and fluids of deep origin. In such cases, the need for an interdisciplinary approach is evident, involving knowledge and research methods ranging from geology to volcanology, geophysics, geochemistry, mineralogy and hydrogeology. With particular reference to the functional and structural representation of the geothermal system of the island of Ischia and the resulting correlations with the volcano-tectonic processes, the examination of previous information highlights the need to update and improve the knowledge on groundwater hydrodynamics and mineralization processes.

Therefore, the present work represents a strong interdisciplinary action that, starting from the design and implementation of a database on the existing geological/volcanological and hydrogeological information, contributes to highlight the critical issues, define an operating scheme of the hydro-geo-thermal system of the island of Ischia, and upgrade its hydrogeological, geochemical and volcanic monitoring system, in order to contribute to the mitigation of volcanic and related risks. The knowledge of groundwater dynamics and pathways, in fact, is of fundamental importance for understanding the water/magma interaction processes in case of re-alimentation of the shallow magmatic system, and the assessment of the possibility of phreatic explosions occurrence. Moreover, the knowledge of the thermal fluids' circulation and the related rock alteration processes is of paramount importance in the definition of the mechanic characteristics of rock masses and their proneness to failure.

This research well fits into the framework of the ongoing studies on multi-hazard assessment at Ischia and is integrated with the actions planned for the DPC-INGV 2019-2021 convention. The preliminary results allowed the realization of a new hydrogeological map of Ischia, improving the definition of the hydrogeological complexes and advancing the knowledge of the groundwater flow conditions.

S11.15 - Poster

In-soil radon emissions at the summit of Stromboli during 2018-2019

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An automated radon station was operative at the summit of Stromboli volcano during 2018-2019 (PZZ station) until mid-July 2019, and overlapping the onset of the paroxysmal explosion of July 3. The utilized electronic radon dosimeter performs passive measurements on the released alpha particles from soil. These are recorded and automatically processed by a multichannel analyzer that subdivides the counts into Regions of Interest (named ROIs). Therefore, the activity of the radon gas can be retrieved by using the counts of ^{222}Rn, ^{218}Po and ^{214}Po. Similarly, the counts for ^{220}Rn (thoron) and ^{212}Po can be measured. Radon data were collected with soil-air temperatures and have been compared with other environmental parameters (air temperature, pressure, humidity and rainfalls) and the satellite MIR-MODIS thermal data collected by the MIROVA system (www.mirovaweb.it).

Radon concentrations were fluctuating from 5000 to about 10000 Bq/m^3 during late spring of 2018, and they were up to about 20000 Bq/m^3 during late November 2018. Since then radon was oscillating within 22000 and 10000 Bq/m^3 during late December 2018. Then it followed an overall decreasing trend until February 2019 with a minimum value slightly above 3000 Bq/m^3. During March-May 2019 the signal shows several peaks (up around 30000 Bq/m^3) with alternating values well below 6000 Bq/m^3, and reaching two minima ranging 510-280 Bq/m^3, respectively. Before and during the onset of paroxysmal explosion of July 3, 2019, radon data were fluctuating between about 6000 and 12000 Bq/m^3 well below the anomalous values recorded in February-March 2007. Thus, it is not excluded that the absence of precursory signals is likely due to the fact that the summit fracture zone, where the station is located, has undergone self-sealing (as indicated by the fluctuating signal with very low radon emissions during March-May 2019).

The thermal values recorded by the MIROVA system during the whole period are essentially below 3 MW, with very few sporadic anomalies ranging 18-20 MW, and this is substantially consistent with the timeseries of radon emissions being typical of a rather mild Strombolian activity. However, on June 29, 2019, the thermal signal reaches 36.5 MW and drastically increases after the onset of the July 3 explosion.

It is interesting to note that the radon signal is decoupled from temperature data particularly during the late spring-summer season and the contribution of atmospheric pressure marginally affect radon emissions. Future work should be oriented in experimentally tracking the signature of the isotopes of the radon progeny on selected samples of the last eruptive cycle.

S11.16 - Poster

Signature of the 24th December 2018 eruption of Mt. Etna on the chemical composition of bulk deposition in the Siracusa area (Italy)

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Mt. Etna, in the eastern coast of Sicily (Italy), is one of the most active and most intensely monitored volcanoes of the planet. It is widely recognized as a big source of volcanic gases, such as CO_2, SO_2 and halogens, to the troposphere in the Mediterranean basin, and its gas emissions account for a significant percentage respect to the worldwide average volcanic budget. The SO_2 flux from Mt. Etna's plume has been routinely measured by the INGV since 1987. SO_2 flux ranges between 600 to 25000 Mg/d; fluxes greater than 100000 Mg/d were prevalently measured during eruptive events. During eruptive periods, Etna's emissions can be dispersed over long distances and cover wide areas of the Mediterranean region.
Mt. Etna is also considered a huge source of many trace elements to the atmosphere on regional and global scale.
On the morning of December 24th 2018, a moderate lateral eruption of the Mt. Etna started. This eruption was related to an intrusion of a magmatic dike on the high eastern flank of the volcano, through a 2 kilometres long fracture in the NNW - SSE direction. At the same time, the summit craters produced a continuous strombolian activity generating a very dense ash plume, dispersed by the wind into the S/SE direction.
From June 2018 to June 2019, atmospheric precipitations were collected in the area of Siracusa, a city on the east coast of Sicily, about 80 km SSE of Mt. Etna, and in the area of Milazzo, a city on the northern coast of Sicily. Atmospheric precipitations were monthly collected through a network of 12 pluviometers; the collectors were open during the entire exposure time, receiving both wet and dry deposition (bulk collectors). All the collected water samples were analysed for major ion contents and for a large number of trace elements by ICP-OES and ICP-MS.
During the eruptive period (from 24th to 27th December 2018), the prevailing winds blew from the North direction and there were light rainfalls in the monitored sites (between 0.2 mm in Siracusa and Augusta, and 1.6 mm in Palazzolo Acreide). As a consequence, gases and particles of Etna's plume were carried for long distance from the emission point, and they were deposited as dry and wet deposition also in the area of Siracusa. During the eruption event and in the following days, the plume reached distances of more than 300 km from the emission point (island of Malta).
The samples collected in the study area of Siracusa during the period straddling the eruptive event are characterized by high concentrations of some major ions, such as Fluoride (up to 0.88 mg/l), Chloride (up to 124 mg/l) and Sulphate (23.1 mg/l). These ions derive mainly from the emitted volcanic gases (HF, HCl and SO_2).
The effect of the described eruption is also visible in the high concentrations of some trace elements, such as Aluminium, Thallium and Tellurium. The mean concentrations of the selected trace elements in the samples collected in the area of Siracusa, in the period before the eruptive event, are: 18.2 µg/l for Aluminium, 0.009 µg/l for Thallium, while Tellurium was always under

the detection limit (0.004 µg/l); the concentrations of the same elements in the samples collected during the eruptive event reach 152 µg/l for Aluminium, 0.16 Âg/l for Thallium and 0.025 µg/l for Tellurium, therefore showing a strong enrichment.
While Thallium and Tellurium are highly volatile elements typically enriched in volcanic emissions, Aluminium is a refractory element that was probably released by the dissolution of the related volcanic ashes.
The study area of Milazzo, due to the prevailing winds from the North direction during the period of the eruption, has not been affected by the plume and therefore the signature of the eruption is not visible in the samples collected in that area, as shown by the mean values of the selected trace elements: 24.2 µg/l, 0.026 µg/l and < 0.004 µg/l for Aluminum, Thallium and Tellurium respectively.
In conclusion, close to active volcanic areas, volcanic emissions have to be considered among the major contributors to the chemistry of rainwater, especially during eruptive periods.

S11.17 - Poster

S12. CAMPI FLEGREI: INTER-DISCIPLINARY APPROACH TO THE STUDY OF A HIGH-RISK CALDERA

Conveners:
Claudia D'Oriano (INGV-PI), Chiara Montagna (INGV-PI),
Ilenia Arienzo (INGV-OV), Rosella Nave (INGV-OV)

A review on the eruptions of the Campi Flegrei caldera with focus on the possible trigger mechanisms

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The Campi Flegrei caldera is a nested structure, which formed during two main collapses associated with the Campanian Ignimbrite (39 ka) and Neapolitan Yellow Tuff (15 ka) eruptions. Volcanism in the last 15 ka occurred within the younger caldera, and was concentrated in three epochs separated by two periods of quiescence. The last event occurred in AD 1538, with the formation of Monte Nuovo. The volcanism of the Campi Flegrei often shows evidence of magma mixing. Noteworthy, most violent and catastrophic volcanic eruptions on the Earth have been triggered by refilling of a felsic volcanic magma chamber by a hot and more mafic magma. Famous examples include Vesuvius 79 AD, Krakatau 1883, Pinatubo 1991, and Eyjafjallajokull 2010. Since the first hypotheses about the origin of mixed igneous rocks, a plenty of evidence of magma mixing processes, in all tectonic environments, throughout geological times, has accumulated in the literature allowing this natural process to be definitely embedded in the constellation of the most fundamental petrological processes playing a key role in triggering volcanic eruptions. Here we present a combined review on the volcanological, petrographic and geochemical investigations on volcanic rocks that have revealed compositional variations at different length-scales pointing to a complex interplay of fractional crystallization and mixing/mingling during the evolution of the Campi Flegrei magmatic feeding systems. Furthermore, we will also discuss the evidences of internal and external trigger of several volcanic eruptions and the possible hazard implications for the Campi Flegrei magmatic system.

S12.1 - Presentazione orale

Time scales of shallow magma chamber replenishment at Campi Flegrei caldera

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Ascent of primitive magmas from depth into shallow, partially degassed reservoirs has often been invoked as eruption trigger. The resulting processes of convection and mixing have played an important role both in pre- and syn-eruptive stages in many eruptions of different sizes at the Campi Flegrei caldera in Southern Italy.

We performed numerical simulations of magma chamber replenishment referring to an archetypal case whereby a shallow, small magma chamber containing degassed phonolite is invaded by volatile-rich shoshonitic magma coming from a deeper, larger reservoir. The system evolution is driven by buoyancy, as the magma entering the shallower chamber is less dense than the degassed, resident phonolite.

The evolution in space and time of physical quantities such as pressure, gas content and density is highly heterogeneous; nonetheless, an overall decreasing exponential trend in time can be observed and characterizes the efficiency of the whole process. The same exponentially decreasing trend can be observed in the amplitude of the synthetic ground deformation signals (seismicity over the whole frequency spectrum) calculated from the results of the magmatic dynamics. Depending on the initial and boundary conditions explored, such as chamber geometry or density contrast, the time constant thus the inferred duration of the process can vary. An initial vigorous phase of convection and mixing among the two magma types reaches an asymptotic stage after a few hours to half a day.

Independently, the evolution of pressure in the magmatic system also depends on the initial and boundary conditions, leading either to eruption-favorable conditions or not. Relating the time scales for convective processes to be effective with their outcomes in terms of stresses at the boundaries of the magmatic system can substantially improve our ability to forecast the evolution of volcanic unrest crises worldwide.

S12.2 - Presentazione orale

Crystal-mush reactivation processes by mafic magma recharge: evidence from the Campanian Ignimbrite activity, Campi Flegrei volcanic field, Italy

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The Campanian Ignimbrite (CI) eruption (Campi Flegrei, Italy) is associated to a voluminous pyroclastic sequence of trachytic to phonolitic magma emplaced in southern-central Italy, around 39 ka ago. Its proximal deposits are made up by a basal plinian pumice fallout, followed by several distinct crystal-poor ignimbritic flow units and the topmost crystal-rich Upper Pumice Flow Unit (UPFU). Despite several papers, based on whole-rock analyses [Melluso et al., 1995, Pappalardo et al., 2002; Fedele et al., 2016; Forni et al., 2016], suggest the presence of a vertical geochemical gradient along proximal-CI deposits, our geochemical and isotopic micro-analytical data on matrix glasses and minerals of the juvenile components from the San Martino proximal-CI sequence, show the presence of two variably evolved melts with a marked change towards more mafic compositions only occurring in the topmost crystal-rich UPFU.
According to recent hypotheses on silicic melt origin, we have interpreted the CI magma chamber in terms of a crystal-mush system [as firstly proposed by Forni et al., 2016]. In this light, our work has pointed out that the CI eruption was fed by two distinct magmatic components: i) the crystal-poor evolved melt, considered to represent the buoyant eruptible magma portion of the CI reservoir, extracted from a cumulate crystal-mush zone during fractional crystallization and ii) the less evolved trachy-phonolitic melts, formed at the base of the CI reservoir.
Indeed, juveniles from all units, with the notable exception of the last erupted UPFU, have i) low crystal content, ii) evolved matrix glass compositions with negative Eu anomalies (0.2-0.6), iii) micro-scale geochemical and isotope heterogeneities and iv) phenocrysts mostly showing disequilibrium textures. On the other hand, UPFU juvenile products show significant differences with respect to those from the previously erupted units, namely i) a marked higher phenocryst content, ii) less evolved matrix glass compositions with positive Eu anomalies (1.0-1.4), iii) higher and variable Sr, Ba and V contents, iv) particularly low and homogeneous incompatible element abundances, v) high-Or sanidine with equilibrium textures and vi) less Sr- and Nd-radiogenic signatures ($^{143}Nd/^{144}Nd$ up to 0.51245).
We have calculated that the unique composition of the UPFU melts derived from multiple evolutionary processes (three-component mixing + crystallization) occurring when new mafic magma recharges at the base of the CI reservoir thermally reactivated the above crystal-mush, being initially unable to infiltrate the crystal-mush, and then started to physically interact with it. The distinct and variable UPFU Nd-isotopes prove that the recharging mafic magma was directly involved in generation the UPFU melts, and did not only act as heat source to remobilise the cumulate mush [as reported by Forni et al., 2016]. We have also demonstrated that variable proportions (40-80%) of the new mafic magma mixed with a crystal-mush melt (CMM)

compound made up of 80% sanidine-melts and 20% interstitial-melts (IM). This process occurred when the mush crystallinity was sufficiently reduced after the low-Or sanidine melting and thus the mafic magma was able to penetrate into the above CMM mixture (plus residual minerals), generating variable and cooler hybrid melts from which different degrees (10-25%) of high-Or sanidine crystallised. The crystallisation degree was probably correlated with the interaction timescale and cooling extent, forming the compositions of most UPFU feeding magma.
Our detailed micro-analytical study not only provides new insight on the structure and evolution of the reservoir prior to the CI explosive eruption, but also shed lights on the complex mechanisms that can occur whenever a crystal-mush is reactivated by new mafic magma inputs.

S12.3 - Presentazione orale

Clinopyroxene growth and dissolution rate: constraints on the deep level ascent rate of a K-basaltic magma from the Campi Flegrei Volcanic District

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The estimation of the magma ascent rate in the Campi Flegrei Volcanic District (CFVD, south Italy) is of paramount significance in terms of volcanic hazard. Indeed, deep-level ascent rates may be the key to understand the triggering mechanisms of volcanic eruptions and are essential for understanding the rates at which magmas are supplied to volcanic complexes. Thus, to investigate the CFVD magmas transport at Moho-lower crust depth and provide an estimate of magma recharge of the deep reservoirs, we assessed the cooling rate and the deep-level ascent rates of K-basaltic magmas by combining the clinopyroxene growth rate determined by high-pressure crystallization experiments with data from crystal size distribution analyses and thermobarometry of clinopyroxenes occurring in the most primitive scoria clasts of the CFVD. In addition, since only few studies have considered the role played by crystal dissolution phenomena during the crystal-melt interaction and crystal growth, we investigated the role of crystal dissolution in the estimation of magma ascent rate by performing a series of dissolution experiments. In particular, clinopyroxene growth and dissolution rates were experimentally determined in a K-basaltic rock from Procida island (CFVD) through a series of experiments performed at 0.8 GPa by using the piston cylinder apparatus available at the HP-HT Laboratory of the Department of Earth Sciences of Sapienza - University of Rome (Italy). Crystallization experiments were carried out at 1030-1250 °C, $1 \leq H_2O \leq 4$ wt.% and dwell times of 0.25, 3, 6 and 9 hours. Overall, growth rate reaches a maximum value in the shortest experiments (~ $3 \cdot 10^{-7}$ cm s^{-1}) decreasing to ~ $1x10^{-8}$ cm s^{-1} in the longest duration runs. Partition coefficients based on the crystal-liquid exchange show that mineral chemistry progressively approaches equilibrium with increasing run duration. Furthermore, the combination of the determined growth rates with data from thermobarometry and from crystal size distribution analyses of clinopyroxenes in the most primitive scoria clasts of the CFVD, suggests that recharge by primitive magma in the deep reservoirs occurs with a relatively high ascent rate of ~ $0.5x10^{-4}$ m s^{-1}. Dissolution experiments, instead, were performed at superliquidus temperatures of 1300 and 1350 °C and dwell times between 0.5 and 2 hours. The calculated dissolution rates are in the order of ~10^{-5}-10^{-6} cm s^{-1} and results significantly controlled by temperature, while they are not pressure and time dependent. The role of crystal dissolution in the estimation of magma ascent rate has been tested for a natural magmatic system, by interpolating the obtained dissolution rates with the textural data of clinopyroxene crystals from the Agnano-Monte Spina pyroclastic deposits at Campi Flegrei (Italy). Calculations indicate that the time required for partial or complete resorption of these clinopyroxene crystals varies from ~0.5 to ~40 hours, and that the effect of crystal dissolution may be relevant on the estimates of magma residence times if significant dissolution occurs during magma mixing processes.

S12.4 - Presentazione orale

Compositionally zoned clinopyroxene crystals record fluctuations in the Agnano Monte Spina (Campi Flegrei, Italy) magma plumbing system

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Zoning patterns preserve a record of magmatic processes over the lifetime of the crystal, from initial nucleation to final quenching upon eruption. Perturbations in magmatic variables (such as composition, volatile content, temperature, pressure, and oxidation state) can result in complex textural patterns of crystal growth and dissolution, with associated changes in crystal chemistry causing crystal zonation. Here a detailed characterization of the complex sequential zoning has been carried out on clinopyroxene crystals erupted during the 4690-4300 a cal BP Agnano Monte Spina (A-MS) eruption, considered as reference event for a future large-scale explosive eruption at Campi Flegrei caldera (South Italy). Particularly, we investigated the compositional record preserved in clinopyroxene crystals from selected sub-units of the A-MS pyroclastic sequence. Detailed concentration profiles (20-600 µm long, spacing 2,5-10 µm) of major elements (Si, Ti, Al, Fe, Mg, Mn, Ca, Na) were measured along different directions in a total of 42 clinopyroxene crystals. The zoning patterns of Fe-Mg and selected elements (e.g. Al, Ti) often consist of two or more compositional plateau with both sharp and/or slightly diffuse boundaries between them. The plateau composition is interpreted to represent growth of clinopyroxene under a constant set of intensive thermodynamic variables (pressure, temperature, composition, fugacity of volatile species), each characterizing a magmatic environment. A detailed systemization of the information stored in the sequential zoning reveals the existence of at least five magmatic environments (ME). These are characterized by different clinopyroxene composition: M0 (Mg#=86-91, number of crystals=27/42), M1 (Mg#=80-84, number of crystals=9/42), M2 (Mg#=72-78, number of crystals=28/42), M3 (Mg#=63-68, number of crystals=2/42) and M4 (Mg# 46-60, number of crystals=2/42). The change in zoning pattern from one plateau composition to another is then equivalent to the transfer of the crystal from one ME to another. This can be accomplished either by the crystal physically moving (transported by melt) from one environment to another, or by the environment itself changing around the crystal (e.g. by cooling, heating or degassing, crustal assimilation etc). We identified main prominent crystal passageways between the environments M0:M2, several connections between M0:M1, M1:M0 and M1:M2 and less abundant passageways between the environments M2:M1, M2:M0, M3:M2, M2:M4 and M4:M2. The large range of chemical compositions and the complexity of the variations recorded in the A-MS clinopyroxenes suggest they experienced a complex growth before erupting, highlighting the intricate connection between deep and shallow magmatic reservoirs/layers beneath the Campi Flegrei caldera and the heterogeneity of the plumbing system of the A-MS eruption.

S12.5 - Presentazione orale

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

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A multidisciplinary analysis of multiscale seismic profiles compared to a new geo-archaeological dataset provided insights into the last ~15 ky deformation of the submerged part of the Campi Flegrei resurgent caldera, off the Pozzuoli Bay (Southern Italy).
The Campi Flegrei volcanic zone has been traditionally interpreted as a nested caldera formed by collapses associated with two main eruptions: the 100-200 km3 Campania Ignimbrite (CI), ~ 39 ka BP [Deino et al., 2004], and the 40 km^3 eruption of the Neapolitan Yellow Tuff (NYT) at ~ 15 ka BP [Di Vito et al., 1999]. The collapse of the central part of the Campi Flegrei associated with the eruption of the NYT was followed by discrete phases of intra-caldera volcanic activity and resurgence [Marturano et al., 2018; Isaia et al., 2019]. Despite the volcanic and tectonic evolution of the onshore part of the caldera has been intensely studied since long, only in recent years the southern part of the caldera presently submerged off the Pozzuoli Bay has been explored using marine geophysical data [Sacchi et al., 2014; Steinmann et al., 2018].
Utilizing a multiscale seismic dataset, we investigated the formation and evolution of the Campi Flegrei caldera. The analysis has revealed the occurrence of transgressive and regressive events both inside and outside (e.g. Procida channel) the submerged portion of the caldera. The caldera infill preserves the seismic record to study and quantify caldera and post-caldera evolution phases, outlining the interplay between volcano-tectonic processes and sea-level variations.
Based on our seismostratigraphic study, we found significant seafloor uplift between ~12.0-9.1 ky and ~5.5-3.7 ky. These periods broadly correspond to known phases of volcanic activity and unrests, suggesting that not only volcanism but also ground deformation were clustered. In contrast, an aggradational fill pattern prevails between periods of uplift, and allow to document two major subsidence phases between ~9.1 and ~5.5 ky and after ~3.7 ky. These subsidence periods are temporally correlated to intervals of volcanic quiescence or minor activity.
After ~2.5 ky, both the resurgent dome and the peripheral parts of the caldera underwent low-rate subsidence which likely reflects a regional trend. The differential subsidence behaviour across the caldera is supported by the analysis of archaeological sea-level markers represented by fishponds, docks and ancient port structures dated from the Bronze Age to the Roman Age. The central caldera sector is well-known or its rich geoarchaeological record of the bradyseism occurred since Roman times (e.g. Villa dei Pisoni, Portus Julius etc.). Positive and negative bradyseismic motions, with an estimated net subsidence rate of 2-3 mm/yr, have notoriously affected the coastal settlement as testified by the presence of strategies adopted to mitigate and to adapt to such changes. Differently, the archaeological markers away from the resurgent dome (e.g. Gaiola fishponds, Posillipo) show a mean subsidence rate of 1-2 mm/yr during the last two millennia. Even though the ground deformations reconstructed in the peripheral rim appears lower than those recognized inside the caldera, they prove that vertical movements of volcanic origin were not always confined inside the caldera rim and may be related to more regional processes.

S12.6 - Presentazione orale

Reconstruction of the presence of cavities in the first subsoil of the crater area of the Solfatara (Campi Flegrei, Pozzuoli, Italy) and potential risk of collapse

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The study concerns the assessment activity ordered by the judicial authorities following a fatal accident during the visit to the Solfatara crater in the Campi Flegrei (private site): a young visitor (and then his parents) fell into one cavity about 2.5 m deep for the collapse of the pavement (vault) on which it had lingered.

The concentration of the H_2S and CO_2 was immediately lethal. The study therefore sought to provide an explanation for the formation of this cavity in the subsoil through indirect (geophysical) and direct (geomechanical tests) as well as laboratory analyzes with geotechnical analysis on surface soil samples taken to document the relative geomechanical consistency of the trampling area of the crater area.

Moreover, through geotopocartographic techniques, a detailed morphological survey was carried out, in order to reconstruct the preferential superficial water circulation (and contextual stagnation of water) of the meteoric waters, also in relation to the boiling mud pool not far away (so-called Fangaia).

The hydrothermal activity coming from the bottom determines a strong process of alteration of the volcanic deposits which, together with the entry of superficial circulation water that is conveyed from the steep and nearby crater walls and consequent long stagnation and percolation along vertical migration routes such as natural local fractures or preferential anthropic routes (for example excavation in trenches for techonological networks such as electricity/water networks or driving fencing piles), involves the removal of disintegrated and fine volcanic material, through underground circulation in tunnels / cavities, leaving the only superficial crust characterized by a greater process of cementing volcanic materials by means of environmental chemical-physical surface processes.

The average thickness of this crust has been estimated to be around 20-30 cm in the whole crater area and, precisely in the area around the incident cavity, numerous cavities in the subsoil have been identified, similar in size and volume to the subject of the accident. Furthermore, in these 30 cm of superficial crust, there are slabs of a few cm, maximum 3-4 centimeters of material much more coherent which determine, for the most part, the geomechanical resistance of the cap, therefore a small craking / fracturing is sufficient to allow the acceleration by infiltrated rainwater, of the disintegration of the material constituting the first subsoil (within the first 2.5 m) of the crater base.

A multitemporal reconstruction of satellite images has also allowed to evaluate the morphological changes of the interior of the crater, in order to study the preferential routes of meteoric water circulation, waters that over the centuries have always allowed to lightly recharge the Fangaia which over the years has not undergone a change (decrease) in surface area.

Summing up, in this investigated portion, we observe the simultaneous presence of dangerous ascents of hydrothermal fluids from below (more than elsewhere) with the consequent strong alteration of the resulting volcanic materials, as well as the convergence of intracraterial superficial meteoric water circulation. Moreover, the depressed local morphology, together with the more than known local action of microfracturing (along the crater rim and in direction of the two “Bocche”) accelerated by the intervention of man on the surface with trench excavations and / or the infixing of palisades, made it inevitable that at that point a passage to the roof of one of the numerous cavities present in the first subsoil opened (and then widened further).

S12.7 - Presentazione orale

A tiny window on the Campi Flegrei feeding system: a melt inclusion based study

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Campi Flegrei is a volcanic field in unrest since at least the 1950. The volcanic risk associated with this nested caldera is among the highest on Earth, due to the high explosivity of its eruptions and the high density of population living in the caldera and its surroundings. Melt inclusions investigation are a powerful tool for assessing the physical-chemical conditions of magma chambers, the nature of primary magmas and their source regions, the pre-eruptive volatile elements content and the degassing mechanisms. Previous works clearly demonstrate that either before the Campanian Ignimbrite eruption (40 ka) or during the last epoch (< 5 ka) of volcanic activity at Campi Flegrei, poorly evolved shoshonitic-latitic melts rose from large depth (8 km) recharging shallower reservoir/s and carrying a huge amount of volatile elements. Such a recharge possibly represents one of the processes able to trigger an eruption and may have occurred several times before the onset of volcanic eruptions.
In order to understand the pre- and syn-eruptive magmatic processes we performed a study on melt inclusions (MIs) trapped in pyroxenes by combining Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) and Secondary Ion Mass Spectrometry (SIMS) analyses, with literature data. We selected products from three eruptions, Astroni 6, Nisida and Agnano-Monte Spina, that occurred in the past 5 ka in the eastern sector of the Campi Flegrei caldera, being under extensional stress regime. Besides, we included few data acquired on products from the high magnitude Campanian Ignimbrite eruption.
The majority of these inclusions fall in the compositional range of the differentiated Campi Flegrei bulk rocks and MIs. However, few MIs from the < 5 ka eruptions are similar to the poorly evolved shoshonitic-latitic Campi Flegrei eruptive products. Dissolved H_2O contents range from ca. 1.3 to 3.0 wt.%, whereas Cl and F vary from 4500-10000 ppm and 2400 to 3500 ppm, respectively. The Campanian Ignimbrite inclusions have the lowest F contents (ca. 1500 ppm). CO_2 content was determined by SIMS and ranges from 400 to 3000 ppm. No correlation is observed between CO_2 and highly incompatible elements, such as Zr, whereas H_2O gently increases at increasing Zr.
From the H_2O-CO_2 pairs we calculated entrapment pressures ranging between 200 and 500 MPa, corresponding to crystallization depths of ca 8-20 km. Our results suggest a relatively deep provenance for the magmas feeding the Campi Flegrei eruptions, in agreement with the local information on the Moho depth estimated at ca. 25 km by Di Stefano et al. [2011].
The evolved nature of the MIs suggests several steps of magma crystallization before melts become able to erupt. These data also testify to the large amount of volatile elements that degas from both the deep and shallow reservoirs feeding the fumarolic activity. The arrival

of fresh, volatile-rich magma can be responsible of the unrest phases which could last for years or decades without causing a volcanic eruption, as well as may represent the driving factor leading to different-scale eruptions.

S12.8 - Poster

Ground and seafloor deformation of the Campi Flegrei caldera by cGPS data

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The Campi Flegrei caldera is a well known and peculiar example of ground deformation (bradyseism), characterized by intense uplift periods, followed by subsidence phases with some episodic superimposed mini-uplifts. A new uplift phase started in November 2005 and, with increasing rates over time, is still ongoing. The overall uplift at cGPS station located at Pozzuoli in the area of maximum vertical displacement, is about 65 cm from 2005 to date.
We provide an overview of the continuous GPS monitoring of the aerial and submarine sectors of the Campi Flegrei caldera including network operations, data recording and processing, and data products.
At present, 25 cGPS stations are operating at CF area and some stations have been active since 2000.
The pattern of the observed vertical displacement is similar at all the cGPS stations (on land and in the marine sector) and the measured uplift decreased progressively with the distance from the caldera center. The seafloor vertical deformation followed the same pattern observed on land.

S12.9 - Poster

The Phlegrean Fields volcano-seismic monitoring network

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In this research the Campi Flegrei seismic network has been studied by means of the investigation of the seismic event dated at the 12th of March 2018. Seismic data have been processed with the NonLinLoc software. In the global approach the problem of the location of an earthquake is solved by calculating the probability distribution for the space-time coordinates of the hypocenter in a predefined discretized volume. This technique is implemented in the numerical code NonLinLoc. The NLL localization code follows the probabilistic inversion formulation. Based on this formulation, the knowledge of the parameters of a given model is described through probability density functions. The network, which is run by the Osservatorio Vesuviano on INGV, Napoli (Italy), is composed of 22 seismic stations located all around the Campi Flegrei caldera. The analysis of the seismic sequence shows that in the week between March 6th to March 13th 2018, 42 earthquakes were recorded, mainly of low magnitude, in the Phlegrean Fields area. The strongest one, of Magnitude 2.4, occurred on March 12th 2018 at 14:09 and was Located in the middle of Pisciarelli and Solfatara area at depths between 1.1 and 2.6 km. It is to note that those are the main areas of hydrothermal activity, supporting the strong correlation between seismic activity and gas emissions at Campi Flegrei.

S12.10 - Poster

The Solfatara volcano (Campi Flegrei, Italy) eruptive sequence: sedimentological, textural and geochemical study and reconstruction of the explosive dynamics

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Forecasting of future eruptive activity is a challenging goal in volcanology and an important element in volcanic emergency plans. The wide range of activity styles from widespread vents commonly seen during post-caldera volcanism is even more difficult to reconcile with any regular spatiotemporal pattern, making the study of this eruptive activity particularly relevant. Over the last few decades, the Campi Flegrei caldera (Southern Italy) has been showing signs of unrest with low seismicity, deformation and increased fumarolic activity. The eruption of the Solfatara volcano, occurred at 4.3 ka, represents an important case study as it sourced from the area where the main signs of reactivation are nowdays recorded.

We report here a study of the pyroclastic sequence erupted during the Solfatara eruption aimed at a reconstruction of the eruptive dynamics. A detailed stratigraphic analysis and sampling of the pyroclastic sequence in proximal, medial and distal facies was carried out during several volcanological surveys. Sedimentological and textural analyses of the deposits included grain-size, componentry, density/vesicularity measurements coupled with 2D and 3D clasts characterization to obtain the main shape parameters, vesicle size distribution (VSD) and vesicle number density (NV). Geochemical analyses (bulk rock and matrix glass compositions) were also performed.

Results allowed to obtain information regarding the dispersal area of the pyroclastic deposits. The total volume of the eruption (0.061 km^3 DRE) was emplaced during two main phases, both heavily controlled by paleotopography. The first phase, characterized mainly by phreatic explosions with the emission of ballistic materials and pyroclastic flows with limited dispersal, was rapidly followed by a second phase characterized by magmatic explosive activity with the production of turbulent pyroclastic flows alternating with tephra fallout events. While during the first part of the eruption the juvenile component was scarce to absent, tha second part is dominated by the presence of juvenile material of trachytic composition. Textural analyses also show a large variability of the juvenile fraction that covers a large range of density and vesicularity, suggesting that the peak phase of the eruption was reached during its second stage, in agreement with vesicle number densities variability along the eruptive sequence. The distribution of vesicle sizes also suggest that the eruption was strongly pulsatory, with multiple bubble nucleation events during magma ascent, as also shown by the emplacement mechanisms of the eruptive deposits.

S12.11 - Poster

S13. THE SUMMER 2019 STROMBOLI PAROXYSMS: A PRECIOUS OPPORTUNITY TO EXPAND THE KNOWLEDGE ON THE VOLCANO

Conveners:
Alessandro Aiuppa (UniPa), Daniele Andronico (INGV-OE),
Mauro Coltelli (INGV-OE), Giorgio Lacanna (UniFi),
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Stromboli paroxysms represent one of the major risks for people living or visiting the volcano, how can we contribute to mitigate their dangerous impact forecasting unpredictable events?

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Stromboli is one of the few volcanoes in the world that presents a persistent eruptive activity, which has given the name at the most typical explosive phenomenon of basaltic volcanoes, the Strombolian activity. Since 1994 a standard video camera on Pizzo Sopra la Fossa of Stromboli records the explosive activity produced by the vents hosted on the Terrazza Craterica located just 150 m below. After the largest lava eruption of the last century, occurred in 2003, the video surveillance system has been improved with the installation of cameras operating in the infrared band, which allowed us to record several hundred thousand explosive events during day and night, which are populating a database precious for characterizing features and variability of the Strombolian explosions.

The mild Strombolian activity of Stromboli is periodically interrupted by powerful "major explosions" and, in a few extreme cases, "paroxysms". These extraordinary events occur at rates of a few per year (major explosions) and 1-2 per decade (paroxysms), which can be up to three orders of magnitude larger than "ordinary" activity in terms of energy, dispersal and erupted mass. During the 25 years of remote video-surveillance a hundred explosions of higher intensity were classified through the analysis of the images, at begin manually and then in fully automatic way. The continuity between the ordinary explosions and the major explosions was thus ascertained, and for the rare and largest paroxysms could be inferred. Moreover, the temporal trend of the activity highlights a marked increase in the frequency and intensity (ballistic clasts dispersal) of the discrete events before the more energetic eruptive phenomena occur, both explosive and effusive, was qualitatively often observed but not sufficiently quantified yet.

A paroxysmal explosion stroked Stromboli in the afternoon of July 3rd, 2019, without any precursory sign. It was intermediate in size to two other most recent paroxysms (in 2003 and 2007) that had occurred during a lava flow eruption. This highly energetic event resulted into a huge blast, pyroclastic flows entering the sea, and a 6 km high plume deposited a shower of high-temperature spatters on the island's southern flank, down to Ginostra village, causing damages and one casualty.

The image analysis of the Strombolian activity in the months before this paroxysm reveals that a significant increasing occurred about two weeks before, which became stronger with the major explosion occurred in the night of June 25rd, 2019. A similar growth of the eruptive activity was observed also before the 2002-2003, 2007 and 2014 effusive eruptions. The specifics of these increments are under quantitative analysis, which it is possible only for the 2014 and 2019 eruptions because it can be performed on thermal images acquired by a FLIR thermal camera from late 2010 only.

Even if the Stromboli's paroxysms are unpredictable with an useful lap of time to save the people visiting the summit area of the volcano, we can use the recognition of the start of an anomalous behavior in the ordinary explosive activity that can drive to an extraordinary eruptive event, as a precursor for alerting visitors and population on this potential dangerous. The identification of new volcano behavior paradigms and of related monitoring strategies for mitigating the hazard associated to these still poorly understood paroxysmal events, has to be a major objective of the INGV that has its higher social task in the safety of the people living or visiting the Italian active volcanoes.

S13.1 - Presentazione orale

The summer 2019 eruptive activity of Stromboli: new insights on volcano system from observations and field data collection of the July 3 and August 28 paroxysms

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During summer 2019, on July 3rd and August 28th, Stromboli volcano has unexpectedly produced two paroxysmal vulcanian-style eruptions. Paroxysms are short-lived energetic episodes that interrupt Stromboli ordinary, persistent explosive activity and represent a potential risk to visitors climbing to the Stromboli summit. The first paroxysm was preceded by a few precursors: inflation (8 min ca. earlier) at INGV-SVO station, strong ground deformation signal (i.e. 27 mrad at 800 m ca. from LGS-OHO tilt meter) and small lava overflows from all the vents just a couple of minutes before the first paroxysmal sequence. Conversely, the second event was associated to sharp ground deformation signal 5 min before the explosion (i.e. 11 mrad at 800 m ca. from LGS-OHO tilt meter). A swelling of the volcanic edifice explains those deformation signals in both cases. Remarkably, at the beginning of the summer (night between June 25/26) instrumental data and field observations also recorded a so-called strombolian major explosion. Both paroxysms erupted magma from the known elliptical crater terrace area (700-750 m a.s.l.) and generated buoyant ash-gas columns about 4-5 km-high. Ballistic bombs and blocks were ejected at speeds up to 200 m/s as first effect of the overpressurized magma batch ascent and consequent explosion. They represent both the failure of the conduits/craters wall rocks and the early magma clasts ejected. In both paroxysms, immediately after their onset, dilute PDCs flowed on the Sciara del Fuoco (SdF) slope and plunged in that stretch of coast, with a partial planning over the sea surface up to distances greater than 800 m from the coast. The July 3 paroxysm produced two PDCs in rapid succession (Vavg= 47 m/s), one from the SW crater area and another from central one. Tephra affected the entire craters terrace, the volcano summit (magma spatters, blocks) and W-SW slopes of the volcano, involving the Ginostra village, where eyewitnesses accounted for 35-45 minutes-long tephra fallout. In terms of impact and considering the geophysical data available for 2003 and 2007 paroxysms, this event can be considered the highest energy eruption since 1930. The August 28 paroxysm was relatively less energetic respect to that of July 3, with a lower plume height. The eruption occurred from the central vent area and also produced a directional PDC along the SdF, which entered and partly planned over the sea. Ballistics and plume deposition affected the volcano summit but, unlike the July 3 event, the tephra mainly covered the E and NE sectors of the island. Field survey here, recorded numerous dm-sized ballistic up to height of 200 m ca. along the NE flanks of the island and generally decreasing thicknesses of lapilli layer from Scari harbour area to Piscita' suburb. Similarly to July 3, the falling of incandescent ballistics on vegetated areas quickly triggered widespread wildfires in many parts of the island, at elevations as low as 400 m a.s.l.. Witnesses accounted for 33 minutes-long tephra fallout on the Stromboli village that is very similar to what reported for July 3. Another common effect of the two paroxysms was to change the craters morphology. Between the July 3 and August 28 events, activity was dominated by strombolian eruptions, producing intermediate to high lava fountains (up to 350-400 m high), and discontinuously fed lava flows, mainly from the SW-crater. Anomalous geophysical signals

including high tremor and high frequency of VLP (e.g. often 20-30 events/h in the period June 15-September 20) were recorded. SO_2 variations have repeatedly shown daily values above 400 t/d between July and early October. After August 30 the activity progressively waned.
The 2019 paroxysms differ completely from the scenario expected after those occurred in 2003 and 2007 at Stromboli, when they arrived after the effusive emptying of substantial volume of degassed magma, thought to trigger the decompression and fast rise of deep and volatile rich magma.
Data collected on the field after the two paroxysms and early calculations on their respective products distribution evidence that both were directional, in agreement with the very directional nature of the associated pdcs, and fully confirm what observed through thermal and non-thermal cameras. Grain size analysis of tephra revealed unimodal (2-4 mm) gaussian distributions, although secondary modes at fine grain sizes are also present, suggesting the occurrence of syn/post-eruptive aggregation processes. Calculation of plume height and exit velocities derived from isopleths for both the ballistic and the fallout components are in agreement with field-survey. Among the collected rock samples, we observed both dark, dense and porphyritic juvenile scoriae of basaltic composition and olive-brown highly vesicular pumices with lower crystal content (LP) as well as intimately mingled clasts. Although similar in bulk compositions, the strongly different rheological features of these two magma types and how they interact is the key to understand the paroxysm processes. The dynamics of the studied paroxysms is potentially associated with the quick supply of gas-rich and low viscous magma batch from deeper magma storage into the shallow system and its violent interaction (i.e. a sort of explosive mingling) with the high-porphyritic (HP) magma of basaltic composition that usually ponds in the higher portions of the system, feeding the ordinary strombolian activity.
The summer 2019 paroxysms highlighted that open conduit volcanoes such Stromboli can be occasionally highly unpredictable within the current knowledge. During the peak touristic season, when the summit is visited daily by hundreds of people, the volcano is thus able to express much higher risk scenarios and therefore understanding of this eruption in terms of its triggering, precursors and evolution is essential.

S13.2 - Presentazione orale

The 3 July and 28 August 2019 paroxysms at Stromboli

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Stromboli Island is one of the most active volcanoes in the world. The explosive activity occurs from a crater terrace subdivided into 2 main sectors, namely North and South-Central, each one characterized by short-term vents in the form of hornitos, scoria cones and pit-craters. On 3 July 2019, the ordinary activity (consisting of mild to moderate Strombolian explosions) was interrupted by a paroxysmal event up to several times bigger in intensity and magnitude. This eruption caused various hazardous, not only volcanic, phenomena: spatter and bombs fallout along the tourist paths, coarse tephra fallout on Stromboli and Ginostra, the two villages located on opposite sides, pyroclastic density currents (PDCs) in the sea frequented by tourist boats and later tsunami waves and wildfires on the lower slopes. Tragically, there was one victim when a hiker walked at just 200 m above Ginostra.
After the July 3 paroxysm, explosive frequency and intensity became very high coherently with the pattern of most geophysical and geochemical parameters, culminating with the twin paroxysm on 28 August matching a similar eruptive scenario, plus a major event the day after. Both paroxysmal eruptions clearly heavily affected the economy of the island due to the limited access to the volcano. Indeed, they could have been fatal for many people during the summer touristic activity. Here, we seek to compare the two events from a volcanological point of view (e.g., column height, dispersal of ballistics and tephra fallout, triggering of PDCs, etc.). To conclude, we stress the importance of improving our ability to detect and interpret eruptive patterns and phenomena by updating and strengthening the monitoring systems, and if necessary comparing real time observations with all types of monitored signals. This is surely crucial to mitigate the volcanic hazards associated with paroxysmal activity at Stromboli, before another paroxysm threatens the safety of local people and tourists.

S13.3 - Presentazione orale

The 2019 Stromboli eruptive crisis monitored from space: insights on thermal activity, effusion rates and erupted volume

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The 3rd July Stromboli paroxysmal event marked the beginning of about two months long period with concurrent summit effusive and high explosive activity. Notably, an almost continuous phase of coexisting lava outflow and sustained explosions from the summit vents was unprecedented monitored by the ground-based network installed since the 2002-2003 eruptive phase, such as by sensors mounted on different satellite platforms.

Here, we focussed about the capability of tracking the July-August 2019 thermal activity of Stromboli volcano, by combining images acquired from satellite sensors characterised by different temporal and spatial resolution.

The near-real time elaborated MODIS images (1 km pixel size in MIR channel) from the MIROVA system (www.mirovaweb.it), allowed us to daily updated the heat flux sourced by Stromboli giving a proxy of the intensity of the ongoing effusive activity and tracking variation in effusion rates and erupted volumes. During the July-August phase, the radiative power (VRP) retrieved by MIR-MODIS data typically showed oscillations from 30 MW to 460 MW (170 MW, on average), with peaked value up to 3700 MW recorded during the second paroxysm of the crisis occurred on 28th August. We related the observed VRP trend with pulses in the lava flow as a consequence of a complex behaviour of the shallow magmatic system promoting the surface activity.

Periodic Sentinel-2 high resolution images (20 m pixel size in the SWIR bands) showed the drastic variation in the location and the intensity of the thermal activity suffered by the multiple vents located in the crater terrace, particularly in days followed the 3rd July episode, where direct observations or survey in summit area were drastically limited because risk. Moreover, S2 images clearly track the emplacement and the advancement along the Sciara del Fuoco of the lava flow fed by a summit vent located at the SW rim of the crater terrace.

Notably, following the radiant density approach [Coppola et al., 2013], the MODIS derived heat fluxes measured during the effusive activity, are consistent with Time Average Discharge Rate (TADR) values included between the 0.1 m^3s^{-1} to 1.8 m^3s^{-1} (average of 0.5-0.7 m^3s^{-1}). Taking into account these TADR estimates we evaluated that since the 3rd July to the 31st August (end of the summit effusive phase) Stromboli outpoured about 2.7 to 4.4 Mm^3.

Here we stress how the combination of different satellite data from multiple platforms may improve the space-based monitoring of active volcanoes and, as a consequence, the support provided by satellite data on tracking, in near real-time, the evolution of ongoing eruptive phases.

S13.4 - Presentazione orale

Stromboli paroxysms 2019: volume estimation and morphological changes

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The 2019 Stromboli summer was incredibly busy; two paroxysms had dramatically changed the summit craters of the volcano on the 3 of July and the 28 of August. The first paroxysm destroyed the majority of the Central-South crater areas and a new scoria cone started to grow into it. The 9 of July a drone survey, realized in collaboration with the GEOMAR drone group, allowed to obtain the orthoimage and the Digital Elevation Model (DEM) and the 3D thermal model of the island surface. The unmanned aerial vehicle (UAV) used, Wingcopter, has a unique tilt-rotor mechanism. It ensures a smooth and robust transition between hovering like a multicopter and flying forward like a plane, guaranteeing a flight autonomy useful to overfly the all island. During the 3 July paroxysm, part of the material from the eruption and from the collapse of the rim of the C-S area (CS) have generated pyroclastic flows, the rest have been accumulated on the plateau located right away downhill of the crater area. The lava flow field, which was 180 m wide, reached the sea through lava-debris fans and some overflows spread downhill respect to the North crater area (N). The activity has been intense during July and August and characterized by the growing of scoria cones in the crater areas and continuous lava flows spreading in the Southern sector of Sciara del Fuoco (SdF). The 28 of August another paroxysm implicated the crater areas and two pyroclastic flows travelled down the SdF and out to sea. In September another UAV survey, in collaboration with the GEOMAR, was realized obtaining the orthoimage the DEM and the 3D thermal model of the island surface.
The topographic approach (subtraction between two different surfaces) was chosen to calculate the volume gain and loss. The Pleiades derived DEM was used as pre-eruption surface, it was generated from tristereo.
Pleiades satellite imagery of the 13 of June, unluckily it was devoid of the crater area due to the plume. For this reason, it was necessary to combine the Pleiades derived DEM with another one, generated from UAV images of the 20 of June (by the INGV Laboratory HPHT- Sezione Roma1). The DEMs subtraction allowed us to determine the amount of volume loss in the crater areas (about 3 x 10^5 m^3) and the volume accumulated in the south sector of the SdF (6 x 10^5 m^3) as a consequence of the 3 July paroxysm. Moreover, subtracting the July DEM at the September one, it was possible to evaluate the amount of lava flow emitted in two mouths of eruption (about 3 x 10^6 m^3).
These are preliminary results, more elaboration, and volcanological discussionsare still ongoing. However, we proved the usefulness of this technique to map volcanic products, to highlight morphological changes and perform volume estimation.

S13.5 - Presentazione orale

The contribution of LP and HP magma during paroxysmal explosions at Stromboli

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Over the last several centuries, Stromboli is known for its persistent activity, which consists of intermittent mild explosions from vents of the crater terrace that eject scoriaceous bombs, lapilli, ash and lithic blocks [normal or ordinary activity, according to Rosi et al., 2013 and references therein]. More violent, short-lived explosions may also occur. These events can range from small-scale paroxysms [Metrich et al., 2005; Bertagnini et al., 2008], also defined major explosions [Barberi et al., 1993], to large-scale paroxysms, frequently simplified as paroxysms [Bertagnini et al., 2011]. Small- and large-scale events eject heavy rock fragments close to the summit craters and up to the lowest slopes of the volcano, respectively, reaching also the villages of Stromboli and Ginostra. On the whole, normal, small- and large-scale paroxysms differ for the total duration, fall-out volume, mass discharge rate, ballistic size and range, column height [Rosi et al., 2013].
Different type of volcanic hazards (i.e ballistic and tephra fallout, pyroclastic flows, shockwaves, wildfires, landslides and tsunamis) are associated to the above described violent explosions, affecting the areas surrounding the summit craters, but also the inhabited zones, in the case of large-scale paroxysms. For the mitigation of volcanic risk, the scientific community in the last decades aims to investigate the parameters that are potentially precursors of this violent and high-energetic explosive activity. In particular, the contribution of petrologic study (composition of major, trace elements and isotopes in bulk rocks, volcanic glass, minerals as well as textural analyses, componentry and grain-size distribution analyses) of the pyroclasts is mainly addressed to investigate the geochemical features of the volcano's plumbing system that might someway control the transition from ordinary to paroxysmal activity. It's well known that HP magma is erupted during the normal explosive activity and is also involved as component of paroxysms; on the contrary, the role of LP magma during violent explosions is not yet fully understood. Indeed, LP magma is always produced during large scale-paroxysms, but only occasionally in small-scale ones [Schiavi et al., 2010; D'Oriano et al., 2011]. The violent explosive activity of July-August 2019 at Stromboli allowed sampling the products of the 3 July and 28 August 2019 paroxysms, as well as the material of the intense Strombolian activity that preceded these events.
We measured the major elements and Sr-Nd isotopic compositions of volcanic glass and bulk rocks of bombs, lapilli and ash. The preliminary results, to be strengthened with further analyses, are summarized below: i) the products erupted a few days before the 3 July paroxysm show typical HP composition without any evidence of LP magma in the reservoir feeding the explosive activity; ii) the composition of volcanic glass evidences that HP and LP magma, closely mingled, have been erupted during both paroxysms; iii) Sr-isotopic composition typical of LP magma [Landi et al., 2009 and references therein] has not been measured, even in the bulk rocks of distal pumices. Probably the mingled HP component is prevalent on LP one, so that the overall imprint of pumices (bulk rocks) results that of HP magma; iv) Sr- isotopic values in bulk rocks of the products emitted before the 3 July paroxysm, are significantly higher than values of HP and

LP magma reported in literature since 2000 [Landi et al., 2009 and references therein]. Noteworthy, the measured Sr-isotopic values (c.a. 0.7062) are very close to Sr-isotopic ratios of the products erupted in 1980-85 period [Francalanci et al., 2004], which have been no more measured later; v) finally, extending the investigation to six small-scale paroxysm occurring from 2005 to 2010, for which samples collected during monitoring are available, the composition of volcanic glass indicates that both HP and LP magmas fed three 2009 paroxysms of the central/south summit area. During the remaining three, just HP magma has been emitted.
On this basis of the above study, we started to implement the compositional petrologic dataset of to the products produced during paroxysms, with the aim to understand magma dynamics of Stromboli's plumbing system and the relationship between the eruption of LP magma and the size (small- and large- scale) of paroxysmal events.

S13.6 - Presentazione orale

Ascent and vesiculation of magmas during recent paroxysms at Stromboli: a petrological perspective

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There is a general agreement that paroxysmal eruptions are related to the arrival at the surface of undegassed and poorly crystalline magma from the deep part of the plumbing system. The high volume of magma produced during these explosive eruptions and the deep provenance suggests that a large part of the plumbing system has been involved and sampled during magma ascent. The petrological study of products of paroxysmal eruptions is thus an uncommon opportunity to shed light on the magma dynamics within the whole plumbing system of the volcano. If, as in summer 2019, the paroxysms occur in a short time, there is an additional and exceptional opportunity to understand if and how the magma path and magmatic storage conditions change between these two close events.
Thus, we report here preliminary results of a petrological study of products of two paroxysms that occurred during the summer 2019 and some tephra erupted in the meanwhile.
We collected about 10 samples of bombs and lapilli related to both paroxysms and ash associated to the intense strombolian activity occurred between the two large explosive events. On these products a complete compositional and textural characterization has been carried out, including chemical analyses of minerals and matrix glasses, bubble size and bubble shape distribution of both high and low crystallinity portions. In particular, we focused on zoning patterns in minerals and glasses since they potentially record magma interaction processes and timescales.
We compare these new data with those resulting from the study of an historical paroxysm (PST-9 event), in which the involvement of at least 3 magmatic environments (deep, intermediate and shallow) has been demonstrated and for what a huge amount of experimental data are available On this basis we formulate hypothesis on paths and mechanisms of magma transfer and magma degassing before and during the recent paroxysms.

S13.7 - Presentazione orale

Steady-state changes in the plumbing system dynamics prior to the summer 2019 Stromboli paroxysms

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The Present-days activity of Stromboli has been characterised by persistent mild explosive eruptions, ejecting black scoria bombs, over the last several hundred years. Periodically, lava flows and paroxysms interrupt the “normal” activity. A degassed and highly porphyritic magma (hp magma), with a basaltic shoshonitic composition and a shallow level origin (about 3 km) is erupted by the normal activity and lava flows, whereas a slightly more mafic and volatile-rich magma of deeper derivation (8-10 km) and with low phenocryst content (lp magma) is also erupted as pumices by paroxysms. The hp and lp magmas also differ for Sr isotopes and some isotope ratios of the U-Th series [e.g., $^{226}Ra/^{230}Th$, $^{238}U/^{232}Th$; Bragagni et al., 2014].
The hp magmas undergo fast crystallization together with rapid mixing with the periodically refilling lp magmas, which only during paroxysms reaches the surface without mixing with hp magmas. During ascent, the lp magmas pass through an intermediate cumulate crystal-mush zone, recording the highly variable and high Sr-isotope signature of the previous magmas, and transport antecrysts/antemelts into the shallower reservoir. These processes were capable to maintain the shallow hp reservoir in steady-state conditions in which the fast system perturbations caused by the refilling with fresh lp magmas were quickly recovered. Indeed, until 2009 CE activity, matrix glass compositions of lp and hp magmas were usually well distinct and their periodic mixing was only evident from the decrease of Sr-isotopes of both hp and lp magmas with time, associated to specific micro-Sr isotope zoning of minerals.
The activity of period prior to the summer 2019 paroxysms (2009-2018 CE), however, was often characterised by products with matrix glass compositions filling the gap between the typical lp and hp glass compositions and showing well defined mixing trends. This especially happened in 2017-2018 CE activities. Moreover, from 2007 CE onwards, Sr-isotope ratios have reversed their variation starting to increase with time in both lp and hp magmas. Furthermore, in the 2017-2018 CE activity in respect with the previous one, changes were also observed in the relationships between the Sr-isotope ratios of the hp and lp matrix glasses. Based on these results we had reported the occurring of a clear change in the steady-state of the Stromboli Present-days plumbing system [Francalanci et al., 2019; Goldschmidt-Conference-2019] and the 2019 paroxysms just happens during this period of changes in the dynamics of evolutionary processes. Possibly, these changes can be due to mantle source processes variations and/or to modifications in the shallow interaction processes between lp magmas and the crystal-much zone (antecrysts and antemelts), together with variations in the timescale of lp and hp interactions. In any case, it is noteworthy the correspondence between these evolutionary process changes and the eruptive dynamics of the volcano.

S13.8 - Presentazione orale

The monitoring of hydrogen and carbon dioxide at Stromboli volcano

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Stromboli is an open conduit active volcano where the average eruptive activity consists of medium size explosive events (VEI: 1 - 2) and continuous degassing from the volcanic craters. The average eruptive style is punctuated by major and paroxysmal explosions, two of which lastly occurred on July 3, 2019 and August 28, 2019. In particular, the paroxysms' products involve the gas-rich low porfiric magma mingled with the usual degassed high porfiric magma. These events have occurred less frequently in recent years with a frequency of one event over five years on average. Hence the paroxysms which occurred in 2019 focused the attention on Stromboli's volcanic system and were a cause of concern among the local community and people who visit the island during summer.

Stromboli is an ideal natural laboratory to compare the change in the volcanic degassing and the change in eruptive activity. The near-continuous strombolian explosive events ensure the optimal statistic to compare the results of the gas monitoring and the changes in the volcanic activity. This study focuses on the volcanic gas monitoring, namely the H_2 and CO_2 in the ground gases. The carbon dioxide has been targeted because of attains early the saturation during magma ascent toward the surface. Since it was established that the amount of CO_2 emitted by the volcanoes is directly dependent on the amount of magma in the plumbing system, the CO_2 flux measurement became a routine technique for volcano monitoring. The hydrogen concentration in the volcanic gases is related to the water dissociation reaction at high temperature. Thus, it affects the oxidative condition of the magma which has a key role in determining the speciation of multivalent elements, particularly the iron and sulfur speciation, and contributing to volatile partitioning between gas and melt, the crystallization sequence and the magma differentiation. Since hydrogen and sulfur may form different species in magmatic gases, the investigation of the composition of volcanic gases offers valuable insights into the redox properties of the magma feeding the eruptive activity of Stromboli. Still, the oxygen fugacity of the magma is buffered by a number of redox reactions between ferromagnesian minerals and the surrounding melt or rock matrix. Therefore, the hydrogen concentration is expected to generate pulses in the volcanic gases which reflect the departure from and the restoration of the redox equilibrium.

The ground gas monitoring has been performed in the summit area of Stromboli, namely in the north-east of the Pizzo Sopra la Fossa zone, where the volcanic gases discharged from the ground have near 80° C and CO_2 flux was 8000 g m^{-2} d^{-1} an average. The CO_2 flux was measured in agreement with the dynamic concentration method. The hydrogen was detectable in those gases and the average concentration was up to some hundreds of ppm by volume. The hydrogen concentration has been measured through a specially designed electrochemical sensor. The measurements were performed hourly, the data are stored in a memory card and telemetered daily to the INGV-Palermo.

The monitoring activity of volcanic gases has been performed from May 2009 to October 2010. Some major explosions occurred during the time window of monitoring activity and they were correlated with the change in the gas output and the chemistry of the ground gases. The comparison of the dataset with the eruptive history of the volcano indicated that major explosions were preceded by relative increases of H_2 concentration and coupled by relative increases of CO_2 flux. The results of this study demonstrate that the monitoring of hydrogen in the ground gases is an ancillary parameter in the perspective of volcano surveillance.

S13.9 - Presentazione orale

CO_2 and SO_2 plume emissions during the summer 2019 Stromboli unrest

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The Stromboli's summer 2019 eruptive phase has represented a real challenge for the volcanological community. For the first time since the volcano has been instrumentally monitored, a violent paroxysmal eruption has occurred (on July the 3rd) without any lava emissions beforehand (as had occurred in 2003 in 2007, instead). The July the 3rd, 2019 paroxysm has not been preceded by any obvious reported long-term precursory signal, in contrast with the 2007 paroxysm that had been anticipated by several days of unusually intense plume CO_2 emissions [Aiuppa et al., 2010].
Here, we report on a detailed, post hoc analysis and re-interpretation of results acquired by an integrated (UV Camera+Multi-GAS) gas-monitoring network (www.bridge.unipa.it). Based on these results, integrated with and corroborated by independent geophysical, satellite, and volcanological information, we show that the July the 3rd paroxysms was in fact preceded (by a few days) by a mild but detectable increase in the plume CO_2 output, that reached very high values (>2000 t/d) on late June 2019. This brief (a few days long) increase was a factor > 3 lower in magnitude (and shorter in duration) that the precursory signal observed prior to the 2007 paroxysm, and thus remained unreported prior to the event. Yet, the June 2019 CO_2 peak has been the highest since May 2018 (when the network was completed with installation of a Multi-GAS instrument in the Pizzo area).
The July the 3rd explosion caused partial failure of the crater terrace's rim, and ultimately led to drainage of magma (previously stored in the volcano's upper feeding conduits) into the Sciara del Fuoco. This effusive phase was accompanied by a progressive increase of the SO_2 flux (from < 100 t/d to > 400 t/d in less than a month), which we interpret as due to accelerating magma circulation in the shallow plumbing system. Since late July, the CO_2 flux started to increase as well, culminating into the very high values (up to 3000 t/d) observed in the days prior to the August 28th paroxysm. We propose, in line with what previously documented for the 2007 case [Aiuppa et al., 2010], that such CO_2 flux increase was caused by effusion-driven depressurization of the Stromboli deep plumbing system, ultimately culminating into the second paroxysm in less than 2 months.
It is concluded that, in the absence of an ongoing effusion (July the 3rd), the pre-paroxysm precursory CO_2 signal is far lower, and then more difficult to capture, than during an effusion (March 2007 and August 2019). This difference likely implies distinct trigger mechanisms (and

modes and rates of degassing) for the two types of paroxysms (those occurring during an effusive unrest vs. those that manifest during ordinary strombolian activity). A major re-thinking and implementation of the gas-monitoring network is highly required to attempt at a more effecting forecasting of these abrupt and highly hazardous events.

S13.10 - Presentazione orale

Probabilistic hazard assessment of ballistic bombs from paroxysms and major explosions at Stromboli

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On the basis of a critical review of field data related to the dispersal area of ballistic bombs from major explosions and paroxysms occurred at Stromboli, we propose a first probabilistic hazard map of the areas exposed to future events of this kind.
First, a conditional probability map, i.e. under the assumption of having a major explosion or a paroxysm, was calculated on the base of a Monte Carlo simulation varying circular sectors exposed to the bombs. The sectors are assumed to have an uncertain radius, direction, and angular amplitude. Due to the limited number of explosions that are well-mapped, and of possible under-recording of the bombs distribution in some parts of the island, we also performed a sensitivity analysis assuming uniform directions, or a round-angle exposed area.
Then, we combined a temporal model of major explosions and paroxysms based on the available record with these estimates. The result was a map of the absolute annual probability of being exposed to ballistic bombs. Finally, we also produced a preliminary estimate of the spatial density of bombs over square meter in a few specific locations, based on literature review, field work, and satellite imaging.
The spatio-temporal probability maps can also be used to provide first quantitative estimates of the risk rates taken by guides, volcanologists, tourists and people living on the island year-long. The total time that each person spends inside the areas exposed to the bombs, over a year, defines the annual risk taken by the individual. We show that, depending on the memory properties of the temporal models, the risk levels are not constant and they can increase for some weeks after any major explosive event, if compared with their mean statistics.

S13.11 - Presentazione orale

Genesis of tsunami waves generated by Pyroclastic flows and the Early-Warning system

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Pyroclastic flows are a common product of explosive volcanism and have the potential to generate tsunami wave when dense flows encounter bodies of water. Tsunami generated by large sub-aerial mass may constitute a serious hazard for coastal population and environment, as documented by several examples in recent history and by numerous geological traces of paleo-events.

On July 3rd and August 28th 2019 paroxysms at Stromboli volcano produced a few km-high eruption columns, huge tephra fallout and pyroclastic density currents propagating along the Sciara del Fuoco at a mean speed of 70 m/s. These latters generated two moderate high tsunami waves characterized by a period of ~30 s which were recorded at a sampling rate of 125 Hz in the very near-field by two elastic beacons located a distance of 0.3 (PDC) and 1.5 (PLB) Km from the location where the mass flow entered the water. Video camera images and arrival times indicate that tsunami near the coastline was propagating at a mean velocity of 22 m/s. This gave the unique opportunity to detect the tsunami at the source providing an unprecedented record of the tsunami wave when is forming. The tsunami record provides an important constraint for the modelling and it has a large impact on the understanding of the tsunami generated by pyroclastic flows dynamics. The record of the two tsunami is also offering the possibility to test our ability to automatically recognize those long period waves and to trigger the acoustic alarm network installed in Stromboli and Panarea islands and in Milazzo (Sicily). We show how the Early Warning system was able to detect the tsunami providing the alert some minutes before (~ 2 minutes) the waves were reaching Stromboli island providing for the first time an efficient tool to mitigate the tsunami risk associated to the explosive volcanism. Moreover, the high quality of these data recorded in the very near-field is suggesting the possibility of using simple analytical equation to quickly estimate the source parameters of the tsunami in terms of volume per unit width, maximum speed of sub-aerial flow and submerged travel time.

S13.12 - Presentazione orale

The July-August 2019 Stromboli eruptive crisis and the early-warning system for explosive paroxysms

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On the July 3rd 2019, Stromboli volcano erupted with the formation of a convective plume almost 5 km high a.s.l. associated to tephra fallout on the western part of the island and severe wildfires. The violent explosion (paroxysm) generated a pyroclastic flow along the steep slope of the Sciara del Fuoco that, after reaching the coastline, triggered a 2-meters high tsunami wave. After two months of intense and violent explosive activity associated with lava effusion from the summit craters, on August 28th a second paroxysm occurred. s. Intense ash fall hit the village of Stromboli, and the generation of a second pyroclastic flow along the Sciara del Fuoco triggered a second tsunami. We show how these two large explosions are occurring with no clear change of the geophysical and geochemical parameters measured by the permanent monitoring networks. This is opening question on the dynamics of the magmatic system responsible for triggering the paroxysms and with a direct impact on the risk assessment. However, both explosions have generated a large deformation of the ground recorded by tiltmeters as a gradual inflation of the volcano edifice almost 10 minutes before the explosive onset. Both events share the same ground deformation pattern which is coherent with previous paroxysms and major explosive events, thus suggesting an explosive mechanism repeating in time with the same dynamics. The invariance of the ground inflation trend represents the base for the automatic early warning system operating at Stromboli volcano. Ground deformation is thus opening a new perspective on the ability monitoring systems can help in assessing the risk associated with volcanic explosion.

S13.13 - Presentazione orale

Morphological characterization of basaltic pumice from the summer 2019 Stromboli eruption: insights from the Calabrian beach deposits (Italy)

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On the 3rd July 2019, a new powerful paroxysmal eruption at Stromboli volcano (Aeolian Islands, Sicily) occurred. This event was exceptionally energetic so that the basaltic material reached even the Calabrian coasts by floating on water. In this work, several samples of basaltic pumice were observed and characterized in order to constrain their main features linked to this energetic eruptive event at Stromboli and to infer which physical conditions may have determined their floating on the sea water, in order for them to reach several beaches located on the Tyrrhenian coast of Calabria. Basaltic pumices (> 4 cm in size) observed in this work (n = 32) were collected from Nicotera Marina, Cala Janculla, and Praia i Focu beaches (Calabria, Southern Italy); these last are pocket beaches, accessible only via boat, so they have acted as a natural 'trap' for the material coming from the sea, and they served as large accumulation areas for the Stromboli basaltic pumices. A binocular optical microscope was used to infer morphological characteristics, textural features, and to roughly quantify the degree of vesiculation and the abundance of Pele's hairs in these peculiar basaltic pumices. The most evident features are given by magma mingling textures, visible pyroxene crystals (up to 5 mm), as well as vesicles and relatively thick Pele's hairs. In general, only in the basaltic pumice of Cala Janculla beach it is possible to notice the largest vesicles and the most glassy-looking samples; along with the highest degree of vesiculation and abundance of Pele's hairs. While the physical aspect of the basaltic pumices collected in the Nicotera Marina and Praia i Focu beaches looks more scoriaceous or lapilli-like, and with a lesser degree of vesiculation. The morphology and physical features of these basaltic materials may have acted as an efficient way for keeping them floating on the sea water from the Stromboli island to the Tyrrhenian coasts of Calabria. In particular, this could be due to the high abundance of vesicles. In particular, data from this work show that the degree of vesiculation linked to the abundance of Pele's hairs indicate a moderate degree of correlation (R2 = 0.64), suggesting a great presence of interconnected networks of empty spaces in these basaltic pumices. In addition, the presence of large bubbles (up to 3-4 cm in size) would indicate the high efficiency of these particular basalts in floating on the sea water and emphasize the fact that the 3rd July event at Stromboli was characterized by a large release of volatiles.

S13.14 - Poster

Seismic interferometry using deconvolution technique during the July-August 2019 eruption of Stromboli volcano

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Seismic interferometry based on deconvolution algorithm seems to be a very efficient technique to evaluate Green's function, which describes with a good approximation elastic property of the medium through which the seismic wave propagates. The ability to measure in real-time information on changes of the elastic properties of the medium is a key parameter to forecast active ongoing processes. On July 3rd Stromboli volcano has erupted with no evident changes in the geophysical and geochemical monitored parameter opening questions on the magmatic process triggering these violent explosive eruptions and revealing the inefficiency of the monitoring systems to provide timely information on the volcanic hazard. We show that seismic tremor almost one month before the eruption has shown peculiar feature with sudden and frequent increase of the amplitude so far in general referred to as "spasmodic tremor". We show how seismic interferometry using deconvolution can be used to derive Green's function of the media between couple of station day by day also in real time. Preliminary results indicate that in spite of other geophysical and geochemical parameters, tremor contains unused information indicating significant changes in the volcanic structure preceding of almost one moth the July 3rd paroxysmal eruption.

S13.15 - Poster

The 3 July 2019 paroxysmal eruption at Stromboli: textural and geochemical features of erupted magma and comparison with other events of similar intensity

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On 3 July 2019, during a period of mild-to-high level of normal strombolian activity, the Stromboli volcano experienced a violent emission of large volume of magma in the atmosphere, which generated an ash cloud of 5 km-high and a fallout of bombs, lapilli and ash on the village of Ginostra. The big eruption was characterized by a sequence of two closely-spaced in time (10 seconds) explosions: during the first explosion, from the SW crater, a radially distributed spatter shower invaded the topmost part of the volcanic edifice, reaching 700 mt a.s.l; after 10 s, a vertical jet of fragmented material and gas was injected into the atmosphere from the central crater. The strombolian activity remained at high level culminating in a second paroxysm on 28 August. Similar violent explosions have been occurred at Stromboli in the past and are always associated to the ascent of a deep-sited, low porphyritic (lp) and volatile-rich magma. In all paroxysms, the lp magma is emitted as pumiceous fragments extensively mingled with the degassed, high porphyritic (hp) magma, residing in the shallow reservoir, that feeds the ordinary strombolian activity and lava effusion.
Both spatters bombs and lapilli and ash fragments were sampled from the summit area of the volcano and in the Ginostra village, respectively, for textural and chemical characterization of matrix glasses and crystals. Analyses were performed by means of SEM-BSE imaging and EMPA with the aim to reconstructing the structure of the deep plumbing system and gain information about the processes involved during the magma ascent, crystallization and degassing.
Preliminary results indicate that lp pumices have a large range of vesicularity, from highly vesicular pumices to abundant dense terms, characterized by small, rounded and isolated bubbles. No microlites are present in the groundmass, but in some spatter samples tiny laths of plagioclase formed following the relatively slow cooling of their external surface. The hp scoriae have a highly variable vesicularity index, from vesicles-free to highly vesicular clasts, these last being characterized by large and coalescent bubbles, separated by thin septa. Mingling textures between lp and hp magmas are evident both at macroscopic and microscopic scale. The contacts between lp and hp portions are commonly sharp, with local hybridization phenomena.
Lp and hp matrix glasses cover the same compositional fields of the products emitted from past eruptions. In particular, the hp glassy matrix is clustered around a CaO/Al_2O_3 ratio of 0.43-0.48 (K_2O 3.8-4.4 wt. %), while lp glassy matrix covers a range of CaO/Al_2O_3 ratio between 0.65 and 0.58 (K_2O 1.8-2.3) at constant FeO/MgO ratio. The lp composition overlaps that of the less evolved products of one of the most powerful paroxysms occurred at Stromboli in historical time (aged at about 1600 AD), and possibly can be related to a fractionation of diopsidic pyroxene Â±Fo-rich olivine at depth [La Felice and Landi, 2009]. Intermediate compositions originated by hybridization phenomena along the contact between the lp and hp products follow a mixing trend between the two end members.
The mineral assemblage of the hp magma is dominated by euhedral, concentric zoned plagioclase associated with large crystals of zoned pyroxene and homogeneous olivine. The mineral paragenesis of the lp magma includes Fo-rich olivine associated with diopsidic pyroxene.

Different crystals of pyroxene and olivine not in equilibrium with the magmas involved in the eruption (both lp and hp) are present in the lp pumices. In addition, plagioclase crystals inherited by the hp magmas are common in the lp pumice. These plagioclases are characterized by dissolved cores surrounded by sieved-textured rims, which generally indicate concomitant processes of dissolution and rapid growth under water degassing [Landi et al., 2004]. The presence of minerals in disequilibrium is also a feature of the products of other paroxysms [La Felice and Landi, 2009] and testifies the interaction with a cumulitic body during the ascent of the lp magma, followed by the syn-eruptive and or pre-eruptive mixing between lp and hp magmas.

The final goal of the study will be pursued by comparing the chemical, mineralogical and textural features of the products emitted during the 3 July 2019 paroxysm with those from other violent explosions (both historical paroxysms and paroxysms occurred in the past 20 years), in order to improve the conceptual model for the deep plumbing system, to understand the interactions with the rising magma and to better define the interface zone between the two magmas.

S13.16 - Poster

S14. FROM MULTI-HAZARDS ASSESSMENT TO RISK REDUCTION IN VOLCANIC AREAS: HOW SCIENTISTS AND DECISION MAKERS COOPERATE FOR FUTURE CRISIS MANAGEMENT

Conveners:
Raffaele Azzaro (INGV-OE), Chiara Cristiani (DPC)

A novel strategy to enhance kinetic energy models by considering channelization processes of PDCs

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Kinetic energy models are tools able to provide an estimate to the inundation area of pyroclastic density currents (PDCs). We present here a novel strategy that allows improving these models in order to consider the occurrence of channelization processes of pyroclastic material. In this strategy, the inundation area associated with a basal collapse process, represented by a root conoid that interacts with the topography, is complemented with the inundation zones derived from the inclusion of secondary source points located in the expected zones of pyroclast channelization (represented by branch conoids). For that, we adopt a tree branch-like structure and appropriate assumptions for setting the position and the initial characteristics of the secondary source points. Two widely used kinetic models are modified by applying this strategy: the energy cone and the box model, giving place to two open-source and freely downloadable codes (ECMapProb and BoxMapProb). We tested these branching formulations by comparing their results with those derived from the traditional formulations of these kinetic energy models, with other numerical solvers, and with the invasion area of real PDC deposits. We show the capability of the presented strategy of improving the accuracy of kinetic models without adding new, unconstrained input parameters or significantly increasing the computational cost, allowing the assessment of volcanic hazards using a probabilistic approach. The application of this strategy represents a time-effective alternative to the use of more sophisticated models for describing PDC transport and deposition.

S14.1 - Presentazione orale

A geological DATABASE as a valid support to evaluate the hazard from volcanoclastic mass flows in the Campanian Plain and surrounding areas

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The circum-volcanic areas can be affected by hazards related to fallout and pyroclastic current deposits that usually reach considerable distances from the eruptive vents. These deposits can be remobilized by intensive rainfalls soon after their deposition and generate significant impact on environmental and human landscape.
This study investigastes circum-vesuvian areas involving part of Apennine reliefs, where a large amount of loose pyroclastic deposits, related to eruptions of Somma-Vesuvius and Phlegrean Fields, have accumulated.
All volcanological and archaeological data collected during the last 20 years from drill cores, outcrops, archaeological excavations and stratigraphic trenches, were reviewed and reorganised in a geospatial database where each feature point (i.e. investigated site) contains information about location, volcanic sequences, possible age, archaeological constrains and the stratimetric features. This database has further been implemented with very recent investigations carried out in selected sites of the Plain and surrounding valleys. It contains more than 400 investigated stratigraphic sequences selected sites.
The stratigraphic analyses have allowed the identification of primary volcanic deposits and the overlying reworked sequences, paying particular attention to the deposits related to the main Plinian and sub-Plinian eruptions of Somma-Vesuvius occurred in the last 4.000 years (Pomici di Avellino, Pompei, Pollena and 1631 A.D.). The primary deposits and reworked sequences were subject of sedimentological and lithological analyses allowing to define paleosoils, erosional or anthrophic surfaces and man-made pre-existences used to define the timing of these deposits.
All these data have been visualized on a Digital Elevation Model (DEM) derived from an airborne LiDAR survey dated 2009-2012. In detail, working on GIS platform, the LiDAR source data were elaborated to obtain the Digital Terrain Model (DTM) that reproduces only the elevation surface of the barren soil at appropriate spatial resolution In addition, the database and DEM were used as main reference for evaluating the spatial distribution of the primary and secondary deposits and as input data for the subsequent modelling of invasion areas generated by volcanoclastic debris flows. The research has been carried out in the framework of the DPC-INGV Agreement B2.

S14.2 - Presentazione orale

A multidisciplinary study for the definition of lahars probabilistic hazard maps at Vesuvius

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In the past four centuries, volcanic mudflows generated by the remobilization of pyroclastic deposits material, commonly known as lahars, have caused between 15% and 20% of all volcanic fatalities. For this reason, it is important to quantify the risk associated to such phenomena by combining different approaches such as field, modeling and probabilistic studies.
In Italy, lahars pose a particularly high threat to population and infrastructures in the circumvesuvian Plains and in the adjacent Apennine valleys, as testified by the geological and historical records. The deposits most affected by heavy rain mobilization are both fallout and pyroclastic flows, mainly related to recent plinian and sub-plinian eruptions of Vesuvius. The assessment of the hazard associated with lahar must consider several aspects that include i) the identification of potential areas of origin, ii) heavy or persistent rain events able to generate deposit mobilization, iii) the extension and the characteristics of the potential flow, iv) the ability to modify the flow properties along the path related to water content, erosion and solid load deposition (which can alter the topography), v) the frequency of such events in the past. Here we present the results of a multidisciplinary effort to tackle these points for the Vesuvian area, carried out within the collaboration between Istituto Nazionale di Geofisica e Vulcanologia and the Italian Department of Civil Protection. Field studies have shown that areas involved in the deposition of lahar associated with past eruptions are much wider than those directly affected by the deposition of primary products of the eruptions. Field and laboratory investigations allowed, for selected cases, the characterization of the source and the invasion areas, the lithological and sedimentological properties of the mobilized deposits and their interactions with the pre-existing topography. Particular attention has been posed to the syneruptive lahars of the 472 AD eruption, characterized by the greatest areal distribution in the northern plain and Apennine valleys. Field and laboratory data analysis were used to calibrate and define the source area for an ad hoc numerical model based on the shallow layer approach. The model has been first validated with analytical solutions, then used to perform a sensitivity study and finally to produce probabilistic hazard maps in the circumvesuvian area.

S14.3 - Presentazione orale

Eruption forecasting and hazard assessment at INGV during the 2019 crisis exercise at Campi Flegrei

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On 16-19 October 2019, the Italian Civil Protection (DPC) organized a crisis exercise at Campi Flegrei (ExeFlegrei 2019) to verify internal procedures and communication flows towards/from institutions and towards population. At INGV ExeFlegrei allowed to verify monitoring workflows and to test and upgrade operational procedures for real-time eruption forecasting and hazard assessment. As regards the latter aspects, after each issued bulletin (time t0), the INGV team provided in real-time:

1. in terms of eruption forecasting, probabilities (with 80% confidence interval) for unrest, magmatic unrest, and eruption in the month following t0, based on BET_EF model [Marzocchi et al., 2008] calibrated in a long series of past elicitation experiments [Selva et al., 2012a].
2. in terms of scenario forecasting, spatial probability maps for vent opening according to two models (Selva et al, 2012b; Bevilacqua et al, 2015; 2019), conditional on the occurrence of an eruption. Both models follow a Bayesian approach, so both the maps were described by a best-evaluation map (aleatory uncertainty), and percentile maps (epistemic). Also, they contained long-term information from Campi Flegrei morphology and geology, and assimilated evidence from the monitoring data given in the bulletin at t_0.
3. in terms of hazard assessment, based on the vent opening maps produced in real-time in 2):
   - hazard and probability maps for tephra load at the ground, conditional to the occurrence of an explosive or of a specific size (so-called Small, Medium and Large explosive scales) eruption. We produced maps for various thresholds in exceedance probability/load, by combining Fall3D model [Folch et al., 2009] simulations of tephra fallout based on Small, Medium and Large explosive scales, run with the most recent wind forecast at t_0. We simulated the tephra accumulated in 24 hours given an eruption onset at t_0, t_0+24h and t_0+48h;
   - probability maps for the invasion of pyroclastic density currents (PDC), based on the box model [Neri et al., 2015]. The PDC size was based on a lognormal statistic of inundated regions by past PDC, and included the main uncertainty on the deposits extent and on a number of not measured but recognized small-sized PDC in the record. PDC size was also correlated to the caldera sector originating the PDC (Bevilacqua et al., 2017);
   - in ExeFlegrei, DPC expressed high interest on “pre-eruptive”; products, i.e., unrest and eruption probability, and vent position probability maps. This may be motivated by ExeFlegrei terminating before the eruption onset, when the Red Alert level (“imminent eruption”) was enforced;
   - due to the short time between subsequent stages in ExeFlegrei and to the high computational cost of mapping, we could not propagate in real-time the epistemic uncertainty on the vent position and on the eruption size to the hazard and probability

maps for tephra load: indeed, only the mean maps were produced, quantifying the aleatory uncertainty only. However, after the exercise end, we retrospectively did it, for the last phase of the exercise, along with an ensemble model of the vent position synthesizing the two Bayesian models.

- From a practical point of view, the number of maps from hazard assessment can grow very rapidly as consequence of considering multiple:
  - threshold values in probability or intensity measure (e.g., tephra load);
  - possible scenarios (e.g., maps conditional to the occurrence of an eruption of any size, or of a specific size, or from the most likely vent position);
  - hazards (e.g., tephra fallout and PDC in this case);
  - maps considering variability in vent opening;
  - percentiles to quantify epistemic uncertainty;
  - forecasting time windows (i.e., t_0 or t_0+24h for tephra fallout).

This can make communication with decision makers difficult and results not fully exploitable in the typical short time of an exercise.

In the light of the experience gained in ExeFlegrei, we conclude that:

- given the relevance for decision makers of eruption and scenario forecast, the models used to provide them should be constantly upgraded as new scientific knowledge is gained, and translated in advance into formalized operational procedures;
- the exploitation of the large portfolio of hazard products, which represents a valuable, quantitative information for taking rational decisions, needs a continuous cooperation between scientists and decision makers. This is a necessarily mutual exchange process: on the one hand, in quiet times the decision makers'; needs should become clearer to scientists, and together they could could conceive priority levels (e.g., high, medium and low) for the products that may go into reports to decision makers and into internal ones. On the other hand, scientists should struggle to better communicate the amount and quality of information carried in their products;
- periodic exercises represent a fundamental opportunity to improve the response of scientists and civil protection to a volcanic emergency.

S14.4 - Presentazione orale

Mitigating the highest volcanic risk in the World: a multidisciplinary strategy for the Neapolitan area

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Neapolitan volcanic area is by far the highest volcanic risk one in the World, due to the presence of three active volcanic areas (Vesuvius, Campi Flegrei, Ischia) with an extreme population density: three million people live within 20 km from a possible volcanic vent. Volcanic risk in these areas is strictly associated to seismic risk, and to other secondary risks as landslides and flooding.
The mitigation of such an extreme risk can only be afforded by considering volcanological, as well as economical, urbanistic and social issues. All these highly multidisciplinary aspects must be jointly recognized and shared by both volcanologists and decision makers, in a global, effective risk reduction policy.
We start considering the very high number of people living in the 'red zones' (the riskiest areas, in terms of the actual emergency plans) of Vesuvius and Campi Flegrei, and the economic losses linked to a complete evacuation of these areas. We then demonstrate, from volcanological considerations, that evacuated people could not come back in the red zones in short times, but rather after years or decades, perhaps never again.
From such basic considerations, we proceed to propose a multidisciplinary, effective mitigation strategy and emergency planning, which can significantly decrease the volcanic and associated risks in the area and to make effectively feasible and sustainable an evacuation, in case of high probability for an impending eruption. The proposed strategy also uses the most advanced Artificial Intelligence methodologies to plan an optimal, complete relocation of the population living in the riskiest areas, in case of sudden as well as progressive evacuation. In addition, our mitigation strategy takes into account other key demographic and economic issues: problems affecting several internal areas of Southern Italy, which can help to handle the problem of risk mitigation, and to possibly jointly solve them.

S14.5 - Presentazione orale

The power of statistical analysis as a tool for an integrated hazard assessment at Mt. Etna (Italy): how earthquakes and flank eruptions move together on a long-term perspective

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Flank eruptions at Mt. Etna volcano are often related to the occurrence of strong earthquakes. Nevertheless, this is not always the case, and the relationship has to be modeled in probabilistic terms using Data Science. The topic has been investigated in a few studies, starting in the 80s and the 90s. This statistical analysis produced a clear result - the objective identification of the correlation of the two phenomena. However, from a quantitative point of view, the results were strongly affected by the limitations in the historical records available at that time, and by the statistical approaches adopted. The research continued afterwards, thanks to the basic research projects funded by the Department of Civil Protection in 2000-2015. This provided more complete and extended knowledge of the eruptive and seismic phenomena, and of their relationships.
The implications for a multi-hazard assessment are significant. In particular, the quantitative analyses performed show that the probability of strong (i.e. damaging) earthquakes is influenced by the occurrence of flank eruptions for several weeks, both during the eruptive activity and after the end. The main target of the study is measuring and modeling how much is probable, if compared to the average pattern, to have an earthquake temporally related to a flank eruption, and how long this statistical influence can last for.
In particular, we perform a time series analysis of both the seismic and eruptive records in the last 145-170 years, choosing the longest available seismic record which we assume to be complete. We included the estimation of the seismic rate and investigated the evidence for rate changes in time, as well as the effect of choosing different sub-records as a function of the scale parameters (e.g. earthquake magnitude thresholds, strain release). The key step in the study is the statistical analysis of the inter-event times, either between events of the same type or between earthquakes and eruptions. This produces quantitative estimates of the earthquake rate under the influence of flank eruptions, describing the behavior of the coupled volcano-tectonic system with the final purpose of performing a multi-hazard assessment.
This research is currently funded by the Dipartimento della Protezione Civile (Italy), as part of the INGV-DPC contract 2019-2021.

S14.6 - Presentazione orale

Simulating damage scenario for the December 26, 2018 Fleri earthquake (Mt. Etna): method calibration and first results

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In this study we approach the problem of developing a method to generate rapid earthquake damage scenarios for the volcanic region of Mt. Etna. This goal is a part of the multidisciplinary risks to which the area is exposed, and can represent an important contribution for the management of volcanic emergencies in cooperation with the Civil Protection authorities. While the estimate of damage to residential buildings is a consolidated practice for tectonic earthquakes - based on a macroseismic method referring to the definition of damage in the EMS-98 intensity scale [Grünthal, 1998] - its applica tion in the case of volcano-tectonic earthquakes should be tested and validated, since the features of very shallow focal depth and strong attenuation of ground shaking in short distances. As a first step for calibrating the method at Etna, we simulated the damage distribution of the earthquake occurred on December 26, 2018, at 02:19 UTC, in the lower southeastern flank of the volcano. With a magnitude M_L 4.8 (M_W 4.9) and a depth of ca. 1 km, this earthquake is one of the most severe seismic events instrumentally recorded in the last 70 years: it caused heavy damage to the villages of Fleri and Pennisi (intensity VIII EMS-98) and widespread phenomena of surface faulting along the Fiandaca fault, the southernmost structure of the Timpe tectonic system. As many other shallow strong shocks in the area, damage distribution in the epicentral area is strongly influenced by the direction of the causative fault and the rapid attenuation of the ground shaking.
Our analysis involves the assessment of the housing vulnerability by using the information at urban scale for residential buildings provided by the ISTAT census data [Censimento generale della popolazione / Istituto Nazionale di Statistica]. The buildings were grouped into six classes of increasing vulnerability (from A to F) based on construction characteristics (typological, morphological and age information). The assessment of damage scenario is computed by means of a macroseismic method [Lagomarsino et al., 2006] that groups buildings into classes of damage according to the five degrees of the EMS-98 intensity scale, given their vulnerability level. We simulated the damage scenario in the most struck municipalities of the epicentral area (Zafferana E., S. Venerina, Acireale, Aci S. Antonio, Viagrande) by assessing the number of damaged buildings or their volume.
In order to test this methodological approach and validate the results, the damage estimates are compared with those collected during the field survey carried out by the INGV-QUEST emergency group.
In the case of the 26 December 2018 earthquake, the INGV-QUEST group made a direct inspection of 33 localities to map in detail the area of maximum damage effects; due to the dense urbanization of the area together with the rapid attenuation of the effects moving out from the epicentral area, the survey was carried out, in some key zones, building by building with the aim to assign intensity according to the EMS-98 macroseismic scale.
Since the distribution of damage was largely concentrated, it is not possible to perform the analysis at a municipal scale, but it is necessary to consider the census section level. Furthermore, the urban settlement is widespread and the localities investigated with the survey

overlap administrative borders (municipal boundaries and census sections). For these reasons the correspondence between the survey data on buildings and those provided by ISTAT, is a further challenge. Our simulations can be profitably overlap with the georeferenced data of vulnerability and damage classes assigned to individual buildings by the INGV-QUEST operators, as well as to the given intensity degree.

A further calibration of the damage estimates will be possible by using the database of buildings damage stored in the AeDES usability forms [Scheda di primo livello di rilevamento danno, pronto intervento e agibilita' per edifici ordinari nell'emergenza post-sismica - AeDES; Baggio et al., 2002]. Such information is collected by the regional Civil Protection agency and regards the post-earthquake survey to assess the effective usability of damaged buildings in order to recovery the emergency as quickly as possible. The full exploration of this database will allow us to collect, classify and compare data related with building and structural features, as well as, other indicators referred to the observed damage reported after a seismic crisis. Possible dataset for further analyses will be those of the following earthquakes: October 29, 2002 (3 events with M_L 4.5, M_L 4.1, M_L 3.9); December 2, 2002 (M_L 3.2); April 20, 2008 (M_L 3.2).

S14.7 - Presentazione orale

INGV Social Communication during Stromboli 2019 crisis

Gruppo di Lavoro INGVvulcani

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Risk mitigation strategies include increasing the awareness of the population on the threat posed by natural hazards, through training and information plans and education programs, aimed at creating a culture of risk.
In order to pursue this objective, the Volcanoes Department of Istituto Nazionale di Geofisica e Vulcanologia (INGV) established the INGVvulcani working group on communication to provide timely, objective, rigorous and authoritative information about volcanoes and their activity as accessible as possible to the general public. This was necessary to counter the tendency of many poorly qualified social media to spread news that are often sensationalistic and alarmist, if not true fake news.
To this purpose, specific INGVvulcani social channels were opened in 2018 to describe volcanoes and their activity: the INGVvulcani Blog, the INGVvulcani Facebook page and the INGVvulcani Youtube channel. INGVvulcani Instagram was opened in September 2019, and Twitter will soon be added to the list.
This presentation illustrates how these channels were used to address the 2019 Stromboli eruptions. During the summer of 2019, Stromboli underwent two paroxysmal eruptions, first on July 3 - costing one casualty - and then again on August 28, luckily with no further victims. Both eruptions occurred during the high tourist season, when the island is particularly crowded, and were not preceded by clear and perceptible precursory signals. As such, both events stirred the media attention, especially the first one, in July. This contribution describes the efforts made by the INGVvulcani working group to provide timely and accurate information on both events. Different kinds of information were shared through various platforms. The Facebook page allowed a quick and frequent online presence, with the fast publication of terse information about the eruption. Images and video (also posted on the YouTube INGVvulcani channel) supported this fast communication. The publication of blog articles, less frequent but longer and more structured, allowed us to provide in-depth information and more details on the ongoing crisis, and on the various volcanic phenomena involved. The home page of the INGV website was also used to emphasise the information, with direct links to all sources of information.
We will summarise the impact of this communication effort (in terms of likes and visualisations), and highlight some unexpected outcomes and future directions.

S14.8 - Presentazione orale

S15. SUBMARINE VOLCANIC ACTIVITY AND ASSOCIATED HAZARDS FROM MULTIDISCIPLINARY APPROACHES

Conveners:
Alessandra Pensa (UniRM3), Annamaria Pinton (UniRM3), Salvatore Passaro (CNR), Riccardo De Ritis (INGV - UniRM2), Guido Giordano (UniRM3)

Atlas of Italian Submarine Volcanic Structures

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During the last 30 years, many studies were carried out on submerged structures in the Italian seas, particularly in the Tyrrhenian area. Despite the increasing amount of information, available data are still far from complete even for the most studied seamounts; in many cases samples or data sources are not well described, often poorly-to-un-georeferenced, or presented on schematic maps, in some cases on poorly detailed bathymetry.

Within the framework of the EMODnet Geology Project (www.emodnet-geology.eu), more than 230 bibliographic references have been identified and analysed, with the aim of identifying and cataloguing the available data on the Italian volcanic seamounts.

A significant original contribution has also been possible by processing the Italian bathymetric map extracted from the EMODnet Bathymetry Project (www.emodnet-bathymetry.eu). The slope maps derived from that bathymetry allowed to infer the areal extent and the volume of the identified seamounts.

Data collected during the compilation of the volcanic seamount database have been standardized, catalogued and summarized in the 57 ID Sheets that form this Atlas and organised in 7 Volcanic Seamount Sectors. Each Sector is briefly described in terms of geographical, geological and geochemical features. In each ID Sheet, all the information related to one or multiple seamounts (belonging to the same structure/group) has been classified in five different categories: Morphology, Volcanic structure, Chemical composition and age, Volcanic products and Brief volcanic evolution. Each volcanic seamount is illustrated in the related sheet by a figure that shows its morphology by the bathymetry slope map, the extent of its base and the top of the structure. The main features of each volcano are also summarised in a dedicated table and a schematic cross-section.

This work represents the first attempt of a systematic classification and cataloguing of the Italian submarine volcanoes, which aims to make all the information easily accessible to the researchers/users/public.

S15.1 - Presentazione orale

Volcano-sedimentary features in the Somma-Vesuvius offshore: recent discoveries in the Naples Bay

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The Somma-Vesuvius volcanic complex is retained to be one of the most hazardous stratovolcano of the world, given its huge activity in recent-times (the last eruption is dated 1945) and its position on the dense-populated coastal sector of the town of Naples, where about 1.000.000 persons live. The Somma-Vesuvius is made up by alternate pyroclastic and lava flow deposits, composing by an older disrupted edifice (Mt. Somma) with an intra-caldera cone (Mt. Vesuvius). New data available in the offshore proximity of the volcanic complex led to the discovering of previously unknown volcano-sedimentary features in the Naples Bay. Marine surveys documented the presence of a large, diffuse number of active fluid emissions and associated seafloor morphologies, like pockmarks, cones, and elongated features. Fluid vents are particularly concentrated on a sub-circular seafloor morphology located between Campi Flegrei and Somma-Vesuvius at a depth of 150-100 m below the seafloor, ~5 km SW off Naples harbor. This morphology is made up by columnar diapirs, with a significant mixing of unconsolidated pumiceous sediments and gas upraising. These sediments, that were sampled at several locations, are organized in a dome-like structure made up by columnar gas-sediment mix known as "pagodas" previously documented in large degassing areas of the deep-sea (e.g., Norway). The gas composition is comparable with that of the Campi Flegrei and it is indicative of a mixing between a mantle source and shallower fluids associated with a poor de-carbonation of crustal rocks. This structure may be indicative of sprouting volcanism, that actually is not involving magmas as can be seen by low temperatures measured on it.

Large amounts of pyroclastic materials intercalated in the Late Holocene sequence of the Bay of Naples including extensive fall, flow and surge deposits along with large volumes of volcaniclastics related to volcano flank collapses are present. Here, two main deposits ascribed to large lateral collapses of the main edifice (debris avalanches) were mapped in this area. Near to the coastline, several magnetized bodies were found, perhaps interpretable as volcanic domes and lava flows that entered the sea during the Middle Ages. A large, undulated facies made by pyroclastic and marine sediments almost occupy the whole planar area of the Naples Bay until the slope break (located at about 180 m below the sea level).

Finally, a peculiar negative morphology was investigated at a depth of about 50 m below the sea level. This morphology consists in a deep hole (about 90 m below the surrounding seafloor) known as the "Bocca dei Pescatori". The presence of such a negative seafloor morphology has been reported by fishermen and included in the official cartography.

The elevated steepness of its inner walls, the ratio between the height of the depression (about 50 m for the exposed section) and its maximum width (30 m), and its convex, upward morphology of the rims in the apical section suggest that the BdP may be interpreted as a collapse feature resulting from an explosion accompanied by huge degassing, which is typical of maars, i.e. low-relief volcanic craters caused by phreatomagmatic eruptions. Although a crater rim is well defined, poorly-defined funnel-like geometry, typical of maar-diatreme structure, can be recognized. Although further constraints on the nature of the sub-seafloor deposits at the bottom of the “Bocca dei Pescatori” are needed, we interpreted its morphology as consistent with those created by maar-diatreme. In summary, recent discoveries in the Naples Bay testify the existence of large areas characterized by slope instability processes, relict of explosive volcanic morphologies and potential items of incipient volcanism in the offshore, for which the marine areas of the Bay should be also considered in the hazard evaluation of this area.

S15.2 - Presentazione orale

The Pozzuoli Bay: a review of recent morpho-structural evolution and unrest dynamics in the marine and onland sector of the Neapolitan Yellow Tuff (NYT) caldera, Campi Flegrei, Italy

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The well-known, active volcanic district of Campi Flegrei (E of Naples, Italy) includes a largely monitored partly submerged collapse-resurgent caldera, ca. 8 km in diameter that formed following the eruption of the Neapolitan Yellow Tuff (NYT), dated ~ 15 ka BP. Since the NYT event, intracaldera activity has occurred episodically along its borders. Dramatic ground deformation associated with caldera unrest has long been recognized over the last thousand years at Campi Flegrei. Significant long-term uplift of the central part of the NYT caldera before 4 ka BP has been documented in the area of Pozzuoli. Caldera unrest during the last decades is testified by two major episodes (1970-71 and 1982-84) of shallow seismicity and ground/seafloor deformation originating uplift up to 3.5 m in 15 years, with maximum rates of 100 cm/year in the period 1983-1984. After 1984, the ground slowly subsided until 2004-2005, when a new of deformation phase and enhanced hydrothermalism started in 2005-2006, with ~0.63 m of uplift at the end of 2019 that leads to an increasing in the monitoring activities.
In the last years, a series of high-resolution multibeam swath bathymetric surveys and LIDAR datasets have provided an overview of the general onshore-offshore morphology of the Campi Flegrei Caldera and Pozzuoli Bay, including major volcano-tectonic elements, landforms and marine bedforms.
The landscape of Campi Flegrei area is essentially characterized by landforms due to an endogenous dynamic, such as positive and negative volcanic forms, highs and depressions of volcano-tectonic origin and fault scarps with superimposed sub-aerial severe areal and linear erosion processes.
The coupling of new geomorphologic (terrestrial-marine DTM) and stratigraphic (reflection seismic profiles, outcrop, gravity core) data yielded detailed additional elements to understand the structure of the Campi Flegrei-Pozzuoli Bay, also including the mapping of volcanic and hydrothermal features across different structural offshore domains (e.g. caldera collar, caldera border and ring - fault system, resurgent dome, and apical graben) and over 80 fluid vents at the seafloor. The use of marine sequence stratigraphic and morphologic (paleo water-depth) indicators supports a better definition of the kinematic evolution and the shallow expression of the deeper structure of the NYT, also including reconstruction of the long-term uplift/subsidence rates.
The inner NYT caldera region is characterized by the presence of a resurgent dome, ~ 5 km in diameter, bounded by a 1-2 km wide ring fault system. The style of deformation of the resurgent structure can be described in terms of a broad antiformal folding, accompanied by subordinate brittle deformation, mostly concentrated in a small apical graben at the summit of the resurgent

dome. The average net uplift rate of the inner caldera resurgence has been in the order of 9-12 mm/year between 10.5 ka PB and 4.0 ka PB, with a total uplift recorded at La Starza, onland, that can be estimated in the order of 60-80 m over that period. Several orders of terraces are present in the coastal proximity, particularly in the northernmost sector of the Pozzuoli Bay. Archaeological remains of Roman age are nowadays submerged at a water depth between 2 and 16 m in depth, along the western infralittoral zone of the Bay, thus indicating a prevailing subsidence in this area since Roman time. Evidences of recent, shallow volcanic structures with a thin marine sediment cover were also detected (e.g., “Monte Dolce”). Relatively shallow volcanic bodies were mapped on the southernmost border of the caldera, i.e. the Penta Palummo, Miseno and Nisida Banks.

S15.3 - Presentazione orale

STEP volcanism in the southern Tyrrhenian Sea: a new volcanic structure offshore Cilento coast

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Tyrrhenian Sea represents a young back arc basin where volcanism manifests itself as arc island volcanoes, large seamounts and spreading like volcanic structures. In the last 2 million years, the eastward roll-back of west-dipping subduction system has triggered thinning and stretching of European upper crust with sporadic emplacement of oceanic crust and formation of huge strato-volcanoes. As in the case of Southern Sandwich, Tonga and Lesser Antille subduction systems, the Tyrrhenian Sea is characterized by a lateral tear fault of the retreating subduction plate with formation of a well developed STEP-like (Subduction-Transform Edge Propagator) system. The Palinuro volcanic complex represents a shallow manifestation of volcanism related to a E-W STEP fault. At east of Palinuro, new geophysical and bathymetric data have revealed the presence of more than 10 unknown volcanic structures most of those showing float top and spreading like feature as confirming that the volcanism occurred in concomitance in a E-W sinistral deformation. The E-W STEP fault system seems to cover a large crustal area with evidence of volcanic intrusion also very close the Calabrian coast.
In the 2017 a new geophysical investigation at north of Palinuro Volcano highlighted the presence of an unknown volcanic features located offshore the Cilento Coast. The new high resolution multibeam and shipborne magnetic data highlighted a spreading-like volcanic morphology and a local low magnetization pattern, features very similar to those observed at east of Palinuro volcanic complex
Inverse and forward magnetic modelling suggest the presence of separate volcanic edifices partially juxtaposed. These new findings raise a new inquiring about the exact distribution of volcanism at the edge of the subduction plate and the real extension of the area affected by the STEP fault.

S15.4 - Presentazione orale

The Diamante-Enotrio-Ovidio seamounts: the easternmost Volcanic-Intrusive Complex formed along the northern Ionian subduction slab-edges (Southern Tyrrhenian Sea)

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Volcanic-Intrusive complexes often formed along lateral slab-edges as a consequence of subduction-induced mantle flow. In this work, we investigate this process in the southern Tyrrhenian Sea where we discovered a large volcanic-intrusive complex developed because of the decompression melting of upper mantle material flowing along a lateral slab-edge. This complex comprises the Diamante, Enotrio, and Ovidio seamounts (DEOS) and extends 50X40 km in the NS and EW directions, respectively. The study is based on the integration of high-resolution geophysical data sets (multibeam bathymetry, multichannel seismic-reflection data, magnetic anomalies, and seismological data). The use of different geophysical methods allowed obtaining responses to a variety of physical properties whose integration have been fundamental to understanding the dynamic and spatio-temporal evolution of the DEOS. The study area corresponds to the intra-slope ridges separating the Sapri and Paola basins. The bathymetry ranges from 120 m to 3000 m and is characterized by a complex morphology due to the occurrence of seamounts, volcanic cones, fault scarps, ponded basins, channelized features (canyons and gullies) and pockmarks. The seamounts form two chains: the southern chain is formed by the E-W alignment of Palinuro, Glabro, Enotrio and Ovidio seamounts, whereas the northern chain is mainly formed by Diamante and an easternmost, unknown seamount (we named Scalea seamount). On seismic profiles, a volcanic belt is inferred throughout the area beneath Ovidio and Diamante seamounts, above the upper continental crust strongly intruded by volcanics. Sills are also inferred on the base of the high-amplitude, continuous and layered reflectors in the lower sedimentary levels. Three fault systems associated with positive flower structures are identified in the north-western sector of the volcanic field. They offset both the volcanics and the sedimentary cover of the Diamante volcano and reach the sea floor. The magnetic anomaly observed in the area is the largest dipole of the northern offshore of the Calabrian Arc and completely overlaps the DEOS area. The 3D inverse model results highlight the source geometry and its relationship with the seafloor. Moreover, the DEOS seamounts are also located in correspondence to a low Vp/Vs anomaly, reaching minimum values of about 1.66. Finally, the volcanic nature of the DEOS is therefore witnessed by: the typical morphology of these seamounts, the analysis of the seismic facies, the existence of magnetized material and the seismic velocities. Additionally, sheet and pillow lavas were also observed through ROV dives on the top of the Ovidio seamount. The direct polarity of the composite magnetic anomaly

A suggests that the volcanic edifices most likely occurred during the Brunhes Chron. Thus, the DEOS activity should be younger than 0,7 Myr. The formation and evolution of the DEOS volcanic-intrusive complex can be framed within the deformation history of the Ionian slab and the mantle flow path. Around 0.6 Ma, a STEP fault associated with lateral lithospheric tearing formed at the northern edge of the Ionian slab. We propose that the formation and upwelling of subduction-induced mantle flow that fed the PVC and DEOS volcanic-intrusive complex was controlled by the STEP fault that limits the northern edge of the Ionian slab. The DEOS volcanic-intrusive complex developed within a strike-slip deformation belt that accommodated the bulk of the shear strain along the roughly E-W trending STEP fault. Thus, the ascent of the melts and its final emplacement was favored by transpressive and transtensive deformation. Our results, integrated with literature data, are significant for the comprehension of the magmatic processes related to the slab tearing occurred in the northern Tyrrhenian-Ionian subduction system, furnishing understandings about the evolution of the subduction-induced mantle flow around the slab edges.

S15.5 - Presentazione orale

Insights of Panarea-Stromboli volcano tectonic interconnections by passive hydroacoustic monitoring of the submarine hydrothermal system off Panarea Island

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The Aeolian Archipelago is nowadays well known to be a multihazard-prone area where volcanic phenomena, seismic events, and tsunamis have occurred several times over the last decades [Romano et al., 2019].
In the eastern part of the Archipelago, a variety of different eruptive periods took place in recent times.
Off the island of Panarea a sudden unrest of submarine volcanic activity occurred on November 2002 induced a submarine explosion that opened a "crater" of 20 by 8 meters wide and 7 meters deep. During the unrest period, the huge degassing activity increased the CO_2 flow rate by some orders of magnitude. Apart from the venting areas already active before the event, the degassing occurred from many new fractures opened at the seafloor along a N40°E trend and from the crater. Estimations before the event indicated a degassing rate in the range of 107 litres/day of CO_2, in contrast with the gas vented during the crisis only by the crater, estimated to be in the order of 1-2 x109 l/d CO_2 [Caracausi et al., 2005].
That event dramatically changed the geochemical features and the degassing rate of the submarine hydrothermal vents spread over the area.
A few weeks later the Panarea degassing event, a flank eruption started at Stromboli volcano [Francalanci et al., 1993] on December 28, 2002, following almost a year of growing explosive activity from the summit craters [Bonaccorso et al., 2003]. A huge flank collapse induced a 20 km^3 landslide producing tsunami waves that caused damages around the island of Stromboli, on other Aeolian Islands and along the Northern coast of Sicily. The most recent effusive eruption along the Sciara del Fuoco took place in 2019, started with a huge paroxysm occurred on the 3rd of July and, as reported by fishermen, followed by short and intense bubbling on the sea surface few miles NW off Panarea island.
These many underwater events pushed the scientists to develop new methods to monitor the sea-floor degassing activity.
Besides the periodical sample collection (gases and hot waters for laboratory analyses), a continuous monitoring has been carried out by a seafloor observatory developed to perform near real-time data transmission [Italiano et al. 2011].
The observatory, deployed off Panarea island, has been equipped with a heterogeneous sensors suite (dissolved CO_2, dissolved O_2, EC, turbidity, pH, temperature and pressure) (Italiano et al. 2011). Among the other sensors the observatory is equipped with a hydrophone in order to record the noise variations of the bubbling gases in a frequency range of 0.5 Hz-3 kHz, emitted at the seafloor as a proxy of the gases outflow variations. First experiments in this sense gave useful information for a tight tectonic link between the submarine volcanic activity of Panarea island and the crater explosions of the nearby active volcanic island of Stromboli [Heinicke et al., 2009].

The acoustic records may provide information on sudden changes not related to natural forces: tides, waves, etc. A continuous monitoring associated to the geochemical features of the vented gases (including helium and carbon isotopic compositions) may provide important and early information on changes occurring at the submarine vents. Moreover, since the hydroacoustic noise is associated to the bubbling activity, every change of the gas flow rate (namely, change of the total gas output) is expressed by an increase in terms of energy (decibels) of the signal in a definite frequency interval. The monitoring activity carried out by passive hydroacoustic recordings; the hydrothermal fluids vented off Panarea have shown significant changes strongly related to the volcanic activity of the nearby Stromboli island.
Data from the continuous monitoring of the submarine hydrothermal vents., showing contemporaneous modifications of the vented fluids and the degassing activity of the nearby Stromboli by mean of CO_2 outflow variations from soils spread over the craters area (Pizzo sopra la fossa area), besides the contemporary variation of the $^3He/^4He$ ratios at both volcanoes, bear testimony to interconnections between the two volcanic islands.

S15.6 - Presentazione orale

Morphostructural analysis of the Graham Volcanic Field offshore southwestern Sicily (Italy) by means of bathymetric data and ROV images

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High-resolution multibeam bathymetric data and ROV images allowed to characterize in detail a submarine volcanic field, named Graham Volcanic Field, located 40-50 km offshore southwestern Sicily [Cavallaro and Coltelli, 2019]. Data were collected in 2012 during a multidisciplinary oceanographic cruise focused on the seafloor mapping and on the geophysical and geochemical monitoring of some volcanic centres located in the NW sector of the Sicily Channel [Coltelli et al., 2016].

The Graham Volcanic Field is located on the western side of a relatively shallow (maximum depth of about 350 m) submarine relief, which also includes the Terrible and Nerita banks. The field comprises a ten of monogenetic tephra cones showing steep slopes and pointy or flat tops and heights from 88 to 144 m. The cones are arranged along a N-S trending and 12 km long belt at 150-250 m b.s.l. The volcanic field includes the relict of the short-lived Ferdinandea Island produced during the well-documented 1831 Surtseyan-type eruption and presently shaping, together with an adjacent submarine cone, the Graham Bank. The present-day morphology of the cones is the result of the interplay between volcanic activity, wave and current erosion, mass-wasting and depositional processes, in relationship with sea-level change, acting in both subaerial and submarine environments.

The morpho-structural analysis of the field has been achieved to measure the main morphometric parameters of the cones. The analysis of some morphological parameters, such as level of erosive activity of the cones slopes, presence and depth of summit abrasion platforms and depositional terraces, in relationship with sea-level change and vertical mobility affecting the area, allowed to reasonably constrain the age of the volcanism at post-LGM (Last Glacial Maximum, 20 ka). This analysis was carried out taking also into account analogies with other submarine volcanic cones worldwide, such as the satellite shoals of Surtsey volcano (Iceland) [Romagnoli and Jakobsson, 2015]. ROV dives allowed to image the top of the Ferdinandea shoal (minimum depth is 9 m b.s.l.), which is characterized by sub-vertical volcanic knolls, and the lava flow (the only one recognised within the entire field) identified on the western flank of the Graham Bank.

The distribution and shape of the cones provide important insights into the interaction between volcanism and tectonics. The alignment of the volcanic cones within the field and the main axis of the clusters in which they are grouped reveal two preferred directions, N-S and NW-SE, respectively, consistent with those of the main tectonic structures of the Sicily Channel.

Another volcanic field, named Terribile Volcanic Field, was also identified on the adjacent Terribile Bank and analysed, suggesting an older age with respect to the Graham Volcanic Field.

The relationship between the morphology of the seamounts and underwater volcanic processes proved the monogenetic nature of this volcanism, which is part of a wider and scattered volcanism affecting the northwestern Sicily Channel. This volcanism represents a peculiarity since it took place within a nearly N-S oriented lithospheric-scale transfer zone (the Capo Granitola-Sciacca Fault Zone) [Civile et al., 2018], associated with the Plio-Quaternary

continental rifting of the Sicily Channel, and thus outside the typical geodynamic settings of other volcanic fields worldwide such as subduction and oceanic rift zones.
Numerous mass transport deposits and pockmarks were also identified in the surroundings of the volcanic fields, suggesting the occurrence of diffuse slope failures and fluid releases, respectively.
The improvement of the knowledge of this submarine volcanism would be also of great interest for volcanic risk assessment, which is mostly associated with the local navigation, being the study area located near to the Sicilian coast.

S15.7 - Presentazione orale

The Kolumbo submarine volcano, Greece: plumbing system dynamics prior to the 1650 CE explosive eruption

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Kolumbo Seamount is the largest of twenty submarine volcanic cones tectonically aligned in the transtentional Anydros basin, NE of the island of Santorini, representing one of the most seismically active zones in the South Aegean Volcanic Arc. Kolumbo explosively erupted in 1650 CE, causing the death of 70 people on Santorini, which is only 7 km distant from the volcano. 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 bsl) [Carey et al., 2013], increasing the hazard of this active system. A possible magma chamber was recognized below the crater at depth 9-6 km by seismic data [Dimitriadis et al., 2009]; this chamber is separated from the storage system of Santorini, as suggested also for the mantle source by geochemical data [Klaver et al., 2016]. It is thus fundamental to know the history of this volcano and to understand its behaviour and, in particular, how its storage and plumbing systems works, to correctly asses risk for the nearby island of Santorini.

We present new petrographic, geochemical and isotopic data (on whole-rock, minerals and glasses) of samples collected during the cruises and by divers. 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 centimetric to millimetric, basaltic-andesitic enclaves. Plagioclase, biotite, pyroxene and amphibole are the main mineral phases; olivine is found in the mafic enclaves. Minerals show quite complex zoning and a large compositional variability (e.g. An15-90 for plagioclase). Fresh lithic lavas were also sampled; they can be subdivided in three groups with characteristic petrographic textures that are well reflected in their different chemical compositions. They can 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.

S15.8 - Presentazione orale

The marine hazard project (WP1) - Preventing the effects of deep sea mining on the Tyrrhenian Sea Seamount

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The lack of mineral resources due to overload of mining areas in subaerial environment call for a new era of exploration aimed to define the possible finding of deposits by the sea. In the last ca. 30 years, most of the international geologic community indicated the exploration of hydrothermal vents in deep marine areas as a potential solution, particularly in those sectors that demonstrated to be useful in the production of polymetallic nodules. Several studies demonstrated the existence of significant concentrations of metals characterized by high economic interest in those areas. Several tests conducted on polymetallic-rich sectors demonstrated the presence of metal rich sediments, also including Gold (2-20g); Silver (20-1200g); Copper (5-15%); Zinc (5-50%) and Lead (3-23%), as well as Vanadium, Nickel and REE (data per ton of material), with an estimated economic value indicatively of about 500-2000 dollars/ton. Therefore, in the next future a new frontier of gold rush will be open, thus probably leading to a new phase of intensive dredging of materials in metal-rich areas that are often dense of biologic activity. This new phase of oceanic exploration may lead to partially known consequences on the marine environment. Marine resources and their utilization are managed through a complex set of legal tools and policies at local to subnational level. To avoid the potential marine environmental degradation, a specific set of rules may be introduced by studying hazard scenarios before a real starting of extraction activities. The main goal of the WP1 Marine Hazzard project develop new scientific and technological approaches for an effective and innovative environmental management, and for an appropriate prevention of effects resulting from deep sea mining and mineral resource extraction in the south-eastern Tyrrhenian Sea seamounts (Palinuro and Marsili, in particular). Most of the proposed solutions to collect nodules from the seafloor involves the use of machines dedicated to extraction of metallic nodules and that destroy the top 10 cm to meters of soft sediment and the associated life, while the high quantity of materials involved may potentially affect the flank stability of the seamounts. To prevent these problems, the Marine Hazard project will explore the existence of potential polymetallic deposits, their average commercial values and the potential hazard related to future dredging activities on the seafloor of specific areas of the Mediterarenan sea.

S15.9 - Poster

S16. HISTORY OF VOLCANOLOGY AND RELATIONSHIPS BETWEEN ERUPTIONS AND HUMAN COMMUNITIES: WHEN VOLCANOLOGISTS MEET ARCHAEOLOGISTS AND OTHER DISCIPLINES FOR INTERDISCIPLINARY STUDIES

Conveners:
Stefano Branca (INGV-OE), Mauro Antonio Di Vito (INGV-OV), Luigi Ingaliso (UniCt), Sara Tiziana Levi (UNIMORE; City University of New York), Franco Foresta Martin (INGV-PA), Maria Clara Martinelli (Parco Archeologico delle Isole Eolie), Daniele Musumeci (UniCt), Alberto Renzulli (UniUrb), Mauro Rosi (UniPi)

Matching lava millstones with volcanoes to unravel transport routes and trade networks in the Mediterranean area from the Roman Empire back to the Phoenicians

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Millstones for grinding cereals were mostly manufactured in antiquity using lava lithotypes, due to their good abrasive properties and durability, independently to their shape (and efficiency). Technological evolution through time saw changes from saddle/flat querns to hopper-rubber to rotary hourglass (Morgantina and Pompeian types). Volcanic millstones are present in numerous archaeological sites throughout the Mediterranean area at significant distances from volcanic sources. Unravelling the provenance of the lava millstones, from one volcano or a volcanic province is therefore of paramount importance to outline transport routes. Evidence for millstone trade networks is also available from several shipwrecks throughout the Mediterranean. These cargos often contain grinding lava stones quarried (and loaded) from the volcanic source area.

Classical igneous petrology such as thin section petrography and major-trace element geochemistry are the main tools allowing the lava millstones to be matched with distinct volcanoes. It is important to note that the footprints of potential volcanic areas exploited to manufacture lava millstones may comprise magmas erupted both in subduction-related (orogenic) and anorogenic geodynamic settings. Basic to intermediate-silica volcanic millstones found in terrestrial and underwater sites and shipwrecks, mostly belonging to the Roman and Hellenistic-Greek time but also dating back to the Archaic Period belong to subalkaline (tholeiitic, calcalkaline, high-K calcalkaline to shoshonitic), sodic alkaline to transitional and high-K alkaline magmatic series.

The most famous archaeological sites to see important leucite-phyric hourglass rotary lava millstones are Pompei and Ostia Antica. Bakeries in these towns were supplied with flour produced by millstones manufactured using a leucite basaltic trachyandesite lava of Somma-Vesuvius or a leucite phonolite lava from the Roman Volcanic Province (Vulsini). The area of exploitation (near Orvieto) of the latter was located about 10 km WNW from the confluence of the Tiber and Paglia Rivers. Here, a fluvial port (Pagliano) represented the collecting point for the millstone trade through the Tiber River down to its estuary (port of Ostia Antica). From this location, most of the Orvieto millstones could easily be shipped (as cargoes or often used as ballast) by different routes throughout the Mediterranean, including far-away provinces of the Roman Empire such as Gallia, Iberia, Tunisia, Tripolitania and Cirenaica. The leucite phonolites from Orvieto represented highly prized raw material to produce millstones, from the Etruscan-Celtic period up to the Late Roman Empire. They even spread towards Sicily (e.g. Poggioreale, Entella), where lava millstones (basalts) were manufactured using lithotypes of Etna, Hyblean Mountains and Pantelleria Island. The latter, due to its barycentric position in the Sicily Channel should be considered as a nodal point for trade in volcanic millstones, in the Archaic Period, i.e. many centuries before the Hellenistic people and the Romans would have largely exploited the basaltic lavas from Etna and Hyblean Mountains for the same purpose. The provenance from Pantelleria is documented for volcanic millstones in Phoenician sites and Carthaginian settlements of Sicily (e.g. Motya and Entella) and Tunisia (e.g. Utica and Carthage) and for those found in the shipwreck cargos of El Sec (off the coast of Mallorca, dated to ca. 4th century BC) and Xlendi Bay (off the Island of Gozo, Maltese Islands, 7th century BC). Pantelleria basaltic millstones were even found at Cádiz (Spain, beyond the Strait of Gibraltar) which is the most westerly Phoenician settlement, ca. 1500 km far from the island itself.

S16.1 - Presentazione orale

Prehistoric human presence on the Etna volcano (Siciliy), in relation to the geological evolution

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The study of human settlements on Etna, regarding in particular prehistory, must take into account the pedological and hydrographic characteristics, with particular reference to the morphology and chronology of the lava flows and the presence of springs located mainly along the periphery of the volcano and rarely at medium and high altitudes. Most of the prehistoric sites are concentrated on the western and northern flanks, since the southern one is almost entirely occupied by lava flows of historical epoch (< 2700 years BP), while on the eastern flank the few sites so far identified are generally found under pyroclastic deposits and soils of considerable thickness.
The oldest human presences are those of the Middle Neolithic (2nd half of the 6th millennium BC), in an area of springs in the territories of Paterno' and Belpasso, and in the territory of Adrano, on the border between the Elliptical volcano lava flow (Piano Provenzana formation, age 40-15 ka BP, from Branca et al. [2011]), and alluvial deposits. These settlements are part of the Neolithic village typology with a predominantly agricultural economy. In the last phase of the Neolithic, at the end of the fifth millennium BC, areas of land more favourable for grazing or itinerant agriculture on a seasonal basis begin to be frequented on a larger scale, generally on Ellittico lava flows. Pastoral activities are demonstrated by the results of archaeozoological analyses of some sites, indicating the prevalence of sheep-goat breeding compared to cattle, as well as by the discovery of typical tools for milk processing. Agriculture required large quartzite tools suitable for a superficial working of the lava soil and millstones for cereals. As in the previous phase, the occasional use of the caves attested, which in these first phases probably served as temporary shelter, even if it cannot be excluded that they began to be used for their symbolic value in relation to the underground world, which would later become prevalent. Indeed, it should be noted that in the vast area of Balze Soprane, on the lavas of Monte La Nave (Piano Provenzana formation), a necropolis was discovered with Neolithic pit tombs.
During the Late Copper Age, after 2800 BC, the human presence at the medium altitudes increased. The settlements of this period are located above lava flows of the primitive Mongibello volcano, (formation Pietracannone, lower member, age 15-3.9 ka BP). In one case (Contrada Marca di Castiglione) on lava of the flow called Alcantara, following a stratigraphic excavation, it was seen that the thickness of the ground preceding anthropization was very modest, such as not to allow agriculture. It should be noted that most of the archaeological sites known for this period, especially in the hills or mountains, are represented by caves. However, they should not be considered places of habitation, even temporary, unless in some particular cases (for example, Grotta delle Femmine, 1,600 m a.s.l.). Instead, they mainly had funerary and symbolic functions, connected to villages located at lower altitudes, especially during the Ancient Bronze Age (2,200 - 1,500 BC), or were periodic meeting places for burials and other ceremonies during presumed seasonal movements linked to pastoralism at higher altitudes. However, there is evidence of open-air settlements up to an altitude of 800 m, as in two cases in the Randazzo

area. The presence of large vessels to contain water demonstrates the importance of the water supply in a substantially deprived. Also, in these two sites, dating back to the Ancient Bronze Age, the lava flows are attributed to the stratigraphic interval 15-3.9 ka BP. At present, the only sites located on lavas (3.9 ka BP-122 BC) are some lava caves on the western outskirts of Catania (1600-1500 BC).
In conclusion, for a first phase corresponding to the Neolithic period, the archaeological data suggests an essentially agricultural occupation. After a long period, corresponding to the fourth millennium BC, for which the data are very scarce, there is a great increase in the number of settlements, even at high-hilly and mountainous levels, which we consider linked to breeding and dry farming in the hilly terrain. This system was probably based on a sort of embryonic organization of the territory more so than on large-scale movements of nomadic groups, at least within the individual areas, with base points and areas destined for seasonal movements.

Human communities living in the central Campania Plain and eruptions of Vesuvio and Campi Flegrei since Neolithic

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Archaeological and volcanological studies revealed that eruptions of Neapolitan volcanoes have interacted with human life since prehistory. The occurrence of high intensity explosive eruptions, interspersed with long periods of quiescence, has characterized the last 10 ka of activity of these volcanoes. Geoarchaeological studies, carried out in advance of investigations for the construction of the Rome-Naples and the new Naples-Bari train lines, made it possible a detailed reconstruction of the human presence in the central part of the Piana Campana up to the coastal strip, between the late Neolithic and the late Bronze Age.
The examined chronological interval includes the sequence of pyroclastic deposits and paleosols overlaying the products of the Pigna S. Nicola (Campi Flegrei, 9533-9201 cal bp) or Pomici di Mercato (Vesuvius, 8890±90 cal. bp) eruptions. The sequence includes the deposits of the following eruptions: Agnano 3 (Campi Flegrei, >4757 cal bp), Paleoastroni 2 (Campi Flegrei, 4712-4757 cal bp), Agnano Monte Spina (Campi Flegrei, 4625-4482 cal bp), at least four units of Astroni, occurred in a short period (Campi Flegrei, 4098-4345 cal bp), and finally the Pomici di Avellino (Vesuvius, 3945+10 cal bp). The presence of palaeosurfaces with evidences of anthropic frequentation, has been important to infer the age of secondary phenomena. The definition isochronous surfaces were useful in making correlations also in absence of diagnostic archaeological findings.
All the geoarchaeological data, collected during ten-year excavations, have been revisited, contextualized and organised in a GIS database. They provide a detailed picture of human settlements and activities through time with a particular focus in the period of occurrence of explosive eruptions of both Campi Flegrei and Vesuvius. Their analysis allows to draw some preliminary conclusions:
Even the recent and final Neolithic show the presence of sites that grow to a maximum distance of 2-2.5 km from the current course of the Clanis river (present Regi Lagni) and along the slope on the edge of the Sebeto river depression, whereas in the surrounding high areas, there is a marked absence of evidence of human presence, as well as in the Sebeto morphological depression characterized by wet-marshy soils both in prehistoric and historical times;
The Agnano 3 and Paleoastroni 2 eruptions accumulated in the Campanian Plain only thin ash beds which do not seem to inhibit the use of the areas, as suggested by the continuity in the use of the landscape for both settlements and agriculture;
The Agnano-Monte Spina eruption determines a significant accumulation of pumice and ash layers, but despite the high thickness, the eruption does not seem to have led to a prolonged break in the use of the areas. The deposit is very permeable and not very cohesive and this has certainly inhibited large alluvial phenomena, has favored pedogenesis and resettlements. Once again, the settlements seem to be located close to the river basins, while we do not have significant evidence of agricultural areas;
The Astroni eruptions, like the other medium-low energy ones already mentioned, do not seem to determine caesuras in the frequentation of the area. The change in the use of some areas seems rather determined by variations in the population structure linked to the mobility of

settlements. The latter is evidenced by the presence of very close settlement nuclei which were evidently not active at the same time;

The deposition of the products of the main phases of the Pomici di Avellino eruption affects the entire territory to the northeast of the volcano and only marginally, during the final phases, the territory under examination. This allowed the migration of the populations living in the area (as well attested in the villages of Afragola and Nola where bronze objects are absent and food and domestic animals also seem to have been largely taken away). Only several hours after the beginning of the eruption the area was affected by arrival of several pdcs at intervals long enough to allow the significant cooling of the ash deposits. In fact, the first footprints recognized in Afragola are imprinted in the first ash deposits, still muddy and cold enough. They are likely relative to people interested in the recovery of objects from settlements;

The area was interested for a long time after the eruption by the occurrence of intense alluvial phenomena that certainly inhibit attempts of re-occupation of the area;

Numerous humans and animals' footprints found at various stratigraphic heights testify passages of organized groups moving away from areas deeply affected by the eruption and subsequent floods and lahars. The post-eruption settlements of the Middle Bronze 1-2 develop only in marginal areas not affected by significant phenomena;

The significant re-occupation of the territory take place only in the Middle Bronze 3, after about three centuries from the eruption.

S16.3 - Presentazione orale

Materials and tools across volcanoes: exploitation of obsidian and other volcanic rocks in Ustica (Italy) during prehistory

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The volcanic island of Ustica (9 km^2) is located in the Tyrrhenian Sea about 58 km north-northwest from Palermo, Sicily, in a strategical position for the routes that lead from the Aeolian Islands to Western Sicily and from Western Sicily to the southern Sardinia. Ustica was settled since Neolithic times until the Middle Bronze Age (about 4000-1300 BC). Since 2017, a paleoenvironmental analysis of the Ustica island has been carried out within the project Brains2Islands, aimed to the investigation of human-environmental dynamics on small volcanic islands of the Thyrrenian sea during prehistory. Surveys and field activities brought to light several prehistoric sites in the island and helped in defining more precisely the settled areas. The island was interested by unsystematic archaeological surveys, excavation campaigns and numerous anthropic activities which, over the last century, have brought to light numerous archaeological remains, attesting an occupation from prehistoric times to today with short interruption phases [Spatafora, 2009; Mannino and Ailara, 2016]. Moreover, the geomorphology of the places makes the island particularly suitable for cultivation activities, as clearly shown by the agricultural exploitation and by the employment of the land during the historical phases [Tranchina, 1982]. All this made possible to outline the settlement dynamics on the island as early as the end of the Neolithic, with the identification of the site of Punta Spalmatore [Mannino, 1998], to date the only site indicated as Neolithic on the whole island. Occupation of the initial and middle Copper ages are instead present in the Grotta Azzurra and Grotta di San Francesco on the south-eastern side of the island and on Piano dei Cardoni [Mannino and Ailara, 2014 ;2016].
As part of the Brains2Islands project, starting from December 2016, new research has been carried out on the entire territory of the island of Ustica, with particular attention to Mezzogiorno and the Colunnella area.
On Piano dei Cardoni, a relevant concentration of prehistoric materials (from the Middle Neolithic to the Middle Bronze Age) was detected in the so-called "supravia" area, which was therefore selected for further research and it is now under stratigraphic excavation and detailed study. The site is attributable to the end of the Neolithic/beginning of the Copper Age (presence of pottery from the Diana culture, incised decorations, white-and-red painted and burnished wares). The area of about 36 sqm so far investigated in Piano dei Cardoni shows therefore the presence of a settlement, whose entity and extension is still to explore and interpret, in order to recreate the framework of settlement pattern and subsistence system at the end of the Neolithic age on a small island after the first human occupation.
In this paper, the analysis of local volcanic lithologies used for manufacturing lithic tools is

presented, together with the classification and provenance of the conspicuous record of non-local obsidian tools. Exploitation of the territory and use of local and/or imported resources from other volcanic/not volcanic areas has been also verified through the petrographic analyses of the ceramic sherds.

S16.4 - Presentazione orale

Life on the edge of the sea in a volcanic island: the geomorphological background of the choice of prehistoric human settlements at Ustica (Palermo, Italy)

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The island of Ustica is located in the Southern Tyrrhenian Sea, 70 km north of Palermo (Italy). It represents the emergent part (8,6 km^2) of a submarine volcano whose activity developed during the Pleistocene and ended ~ 130 ka BP.
This study aims to investigate the geomorphological and environmental causes that conditioned the choice of human settlements at Ustica during the Prehistoric Age, a period characterized by the intense human occupation of the island.
Archaeologists documented the presence of humans at Ustica since the Neolithic Age (~ 8 ka BP), then in the Eneolithic Age (~ 6-5 ka BP), Early Bronze Age (~ 4 ka BP) and Middle Bronze Age (~ 3,4-3,2 ka BP).
The first Neolithic Age settlement was probably built on the flat top of Pirozza hill, on the southwestern sector of Spalmatore. Pirozza hill is a small promontory facing the sea, about 50 m asl, cut on columnar basalts. The top of Pirozza is part of the MIS 7 Crotonian marine terrace (~ 210 ka BP). When observed from the sea, it appears like a fortress. According to the style of ceramic pottery (Stentinello, Trichrome and Diana), some archaeologists suggest that the first Neolithic population landed at Ustica came from Palermo. The Neolithic people settled on that elevated place in order to dominate the south-western sector of Ustica and control the sea between Sicily and the island. The settlement lasted for a long time, and expanded into the surrounding areas, as shown by ceramic fragments still found around the site. In the same area, fragments of obsidian tools were also discovered. As the volcanism of Ustica did not produce volcanic glasses, the obsidian artifacts were imported. The provenance areas of the obsidians, determined by means of geochemical analyses, are Lipari and Pantelleria, attesting the far exchanges between Ustica and the two islands since the beginning of prehistory.
At Piano dei Cardoni, on the southern hinterland of the island, at an altitude of about 100 m asl, another key site for prehistoric presence was found. Until recently, it was thought that the oldest settlement in this part of the island dates back to the Eneolithic (or Chalcolithic) Age. Recently, an excavation essay brought to light also artifacts of the Neolithic Age. In the course of archaeological surface surveys and shallow excavations, many products of the ceramic industry together with abundant obsidian fragments were collected, the latter attributable to Lipari and Pantelleria outcrops too. At Piano dei Cardoni, bedrock is cut on the basalt of Monte Guardia dei Turchi (~520 ka BP), which is covered by Crotonian marine terrace deposits (~ 350 ka BP). The geomorphological features of the area, sloping toward the sea without obstacles, demonstrate reduced defense needs, which were entrusted only to the high coast overlooking the sea. Probably, the improved security in a period between Neolithic and Eneolithic Ages pushed the inhabitants to favor landward sectors which are more protected by salt weathering and prone to agriculture and sheep-farming.
During the Early Bronze Age, the population returned to extremely defended sites. The

settlement referred to this period is located on a small relief called Culunnella. From a geological point of view, Culunnella is the relict of a crater located at the Monte Guardia dei Turchi, in the middle of the island, and it stays at an altitude of about 238 m asl. The top of the hill was reworked by human intervention and its perimeter was protected by basalt counterforts. From that position, a 360° view of the horizon is possible, in order to control the island and its landing sites. The importance of this settlement is testified by ceramic findings in the style of Capo Graziano (Aeolian islands), and by the presence of a necropolis with grotticelle tombs in which ceramic from the same age were recovered.

The most populated settlement of the Ustican prehistory was the Faraglioni Village of Tramontana, which was built during the Middle Bronze Age and was located on a terrace bordered by a 20 m-high cliff overlooking the northern coast of the island. This sector of the coast is formed by the columnar lava of the Gorgo Salato and Tramontana units and is affected by repeated collapses. One of the reasons for the choice of that place is probably related to its topographical and morphological characteristics, which offer a natural protection thanks to the sea cliffs. The structural weakness of the cliffs, characterized by frequent collapses, could also be the reason for the sudden abandonment of the village, which occurred about 3,2 ka BP, two or three centuries after his foundation. Other reasons for this still unexplained abandonment can not be excluded.

Documents and collections for the history of earth pigments and diatomaceous earth ore deposits of Monte Amiata volcano (Tuscany, Italy)

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At the base of the slopes of Monte Amiata volcano (southern Tuscany, Italy), small extinct lake basins of upper Pleistocene age are documented. These lake basins were characterized by the deposition of two very different types of sediment. The first type is a biogenic, predominantly siliceous sediment, consisting of the fossil frustules of microscopic unicellular algae of the Diatomacea family. It has an ultra-fine grain size, is soft and crumbly, with an earthy texture and a pure white color. This sediment is called diatomaceous earth or fossil flour. The second type of sediment is of mixed chemical and biochemical origin with scarce terrigenous components. It derives from the precipitation of iron oxides (limonite/goethite) from low temperature hydrothermal fluids rich in ferrous solutes, assisted by the presence of ferrobacteria. This sediment assumes colors from light yellow to red, brown and black, and has the characteristics of earth pigments. The age of the sedimentation in these lacustrine basins (140-130 ka) is younger than the volcanic activity of the Monte Amiata volcano (304-230 ka), but the presence of earth pigments and diatomaceous earth ore deposits is closely related to the high availability of colloidal silica and ferrous solutes in the mineral, ferruginous and acidic waters draining the volcanic edifice. Both the diatomaceous earth and earth pigments of Mount Amiata volcano are minerals that are widely used by man for various applications since ancient times and they preserve the biological and physical testimonies of the environmental and climatic changes of the upper Pleistocene. For these reasons, they represent geological materials with a fundamental cultural value.

The principal natural earth pigments which were extracted on the lake sediments of Monte Amiata are raw and burnt sienna, raw and burnt umber, and bole. Each of these names represents a natural material with a definite mineralogical composition and peculiar chemical and physical characteristics. The natural earth pigments exclusively mined at Monte Amiata comprise the famous terra di Siena (raw sienna) and terra di Siena bruciata (burnt sienna) that have been ones of the yellow-brown and red pigments most widely used by Italian and European painters from the Renaissance to 19th century (e.i., Giotto, Vasari, Caravaggio, Rembrandt, Vermeer, and Turner). The Monte Amiata earth pigments were of high quality, because they were durable and permanents, transparent or semi-transparent, with good color strength and a high coating efficiency. These excellent properties derived from their composition with a high content of iron oxides and their homogeneity and grain fineness. The first report on the recovery and use of natural earths like pigments in the territory of the city-state of Siena is the Trattato della pittura (Treatise on painting) written in vernacular Italian in the mid-fifteenth century by the Tuscan painter Cennino di Andrea Cennini (1370? - 1440?).

The diatomaceous earths were known since Roman times and were called lactis lunae, agarico minerale, and Terra Lemnia. Literary documents begin in the 16th century, with the descriptions of Andrea Cesalpino, Konrad Gesner, Giorgio Agricola, and Ferrante Imperato. Specific references to the diatomites of Monte Amiata are in the Museo di Fisica e di esperienze by Paolo Boccone [1697], and in the Musaeum Kircherianum by Filippo Bonanno [1709].

The quarrying activity of earth pigments and diatomaceous earths of Monte Amiata was also described by the Florentine botanist Pier Antonio Micheli in 1733. During the 18th and 19th centuries, the earth pigments and diatomaceous earths of Monte Amiata constituted several important geological collections: Targioni Tozzetti in 1776, Baldassarri in 1750, Campani in 1860, Pantanelli in 1867, and Tommi in 1890. They are preserved in the Museum of Natural History of the Fisiocritici Academy in Siena and in the Mineralogy Section of the Natural History Museum of the University of Florence. A particular significance has the collection of botanic, ictiologic, and entomologic fossils collected in the years 1953-1956 by Professor Ezio Tongiorgi in the diatomaceous earth of Monte Amiata, and now preserved in the Museum of Natural Sciences and Territory of Calci (Pisa). All these collections are now particularly valuable because they are the only remaining evidence of the ore deposits in the lacustrine sediments of Monte Amiata.

S16.6 - Presentazione orale

Should I stay or should I go?
6000 years of human presence and abandonments at Stromboli volcano

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Stromboli is the northeastern-most island of the Aeolian Archipelago volcanic arc in the southern Tyrrhenian sea, located in a strategic position for Mediterranean maritime routes and with a rich history of cultural development. The Archipelago has been inhabited, in its most central islands of Lipari and Salina, since the 6th millennium BCE (Early Neolithic). On Stromboli the first human evidence is dated to the 4th millennium BCE, corresponding to the archaeological phase of Late Neolithic/Early Chalcolithic.
The magmas erupting at Stromboli during the whole Holocene are relatively basic to intermediate, and therefore the large explosive eruptions typical of intermediate to high-silica magmas of arc volcanoes are not recorded in this time interval. Nonetheless, the volcano generated catastrophic events, including paroxysmal eruptions and tsunamis.
Recent archaeological investigations reveal a complex occupation pattern with phases characterized by flourishing human presence alternating with abandonments. We present here for the first time a general preliminary reconstruction of the cultural development on the island. The occupation the main archaeological sites (San Vincenzo, Serra Fareddu, Ginostra and Fico Grande) on the island is discussed with new cultural and historical evidence and more than 50 radiocarbon dates, in order to outline human choices over the last 6000 years, during which coexistence with an active volcano could be difficult.

S16.7 - Presentazione orale

Death, Survival and Damage during the 79 AD Eruption of Vesuvius which destroyed Pompeii and Herculaneum

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The eruption of Vesuvius of 79 AD is the first large explosive eruption described in detail by Pliny the Young-er. The eruption began with a high eruptive column depositing a thick airfall pumice deposit to the South East of the volcano, and it was followed by the emplacement of destructive glowing avalanches which destroyed the cities of Pompeii, Herculaneum and Stabiae. In this paper we re-evaluate the succession of the events based on the letters of Pliny, the volcanic deposit and the extensive damages caused also by the earthquakes occurring during the eruption. We estimate the impact of the synchronous seismic activity by evaluating its intensity and effects on the wider Campanian plain and draw-ing novel isoseismal maps. We suggest that the strong intra-eruption seismicity conditioned the behavior of the inhabitants of Pompeii during the eruption, compelling many of those, that were still in the houses to flee from the collapsing buildings. We suggest also a different timing of the travel of Pliny the Elder from that proposed by earlier authors. We infer an earlier destruction of Herculaneum during the first day of the eruption, as wit-nessed by the Elder during his travel from Misenum to the vesuvian region, which compelled him to deviate to Stabiae where he died, the following day, a few minutes after the inhabitants of Pompeii.

S16.8 - Presentazione orale

Mercalli, Wegener and Rittmann's studies on volcanism and orogenesis

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The 20th century represents a golden age in the development of the Earth Sciences. The entire century was animated by numerous debates, from which the basis of the current scientific structures of geosciences would emerge. The most evident result, also known to non-experts, was the formulation of a global tectonic theory: there were to be many formulations until, at the end of the 1960s, the dominant paradigm, Plate Tectonics, was affirmed. Looking at the beginning of the century, one may observe how the geoscientific panorama was very different and rather fragmented. In particular, the study of volcanism and orogenesis was undertaken separately: by investigating the evolution of the study of these phenomena, it is possible to understand how we have arrived at successive conceptions that theorize them in a synoptic view. The work focuses on three scientists: Giuseppe Mercalli (1850-1914), Alfred Wegener (1880-1930) and Alfred Rittmann (1893-1980). These are three famous scientists that have marked the history of the disciplines they investigated. More specifically, we will analyze one text for each character: the first text is Mercalli's "I vulcani attivi della Terra. Morfologia, dinamismo, prodotti, distribuzione geografica, cause" [1907]. This work, centred around the presentation of an overall view of volcanology, contains in chapter IX an important line of research that would lead to the studies of the following decades: a connection between volcanic phenomena and other endogenous and exogenous phenomena of our planet. The second text is Wegener's "Formazione dei continenti e degli oceani" [1976], an Italian translation of the fourth German edition [1929] of his most important text, published a year before the German scientist's death. Wegener is the promoter of a celebrated mobilist vision, namely Continental Drift, the object of numerous criticisms and approvals, as well as able to enliven the debates over half a century: its approach represents a real watershed. The third text is Rittmann's "Vulcani. Attività e genesi" [1944]. Between 1936 and 1944, the eclectic Swiss scientist theorized the first scientific system focusing on magmatology and tectonics, giving a new form to volcanology and inserting it within an organic relationship with the other Earth Sciences. The monograph of 1944, despite being less well-known than the three editions of "Vulkane und irhe Tätigkeit" [1936; 1960; 1981], represents an important step in the comparison between volcanism and orogenesis. The three texts, written or translated into Italian, allow us to follow the comparison and the mutual evolution of these studies: we will see how the questions and answers expressed in the first two texts find a new and important synthesis in the third and final book examined.

S16.9 - Presentazione orale

The discovered manuscript. Mt. Etna for Natale di Pace

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The XVII Century recorded a great number of eruptions that distressed for long time cities, people and territories on the slopes of Mt. Etna. This well-known series of natural phenomena has once again gained attention thanks to the discovery of an unknown manuscript in a famous Portuguese library, which brought new lymph to the interdisciplinary research. The book was written by Natale di Pace, a canon from Bronte, whose life intertwined with those of great political and scientific figures of the time, and with the geological activities of a volcano that, now as then, amazed, shocked and terrified men. My intervention will outline the role of Natale di Pace and of the context where he acted, showing at the same time the solid scientific knowledge of cities 'elites living nearby the volcano and the ability of those cities, quite peripheral, to connect with major European cultural circles.

S16.10 - Presentazione orale

The "Historia Aetnae" of Natale di Pace: a case study

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Beginning in the Seventeenth century, descriptions of Etna began to change: on the one hand there were the traditional works that illustrate the eruptive events and their consequences on the lives of the populations that live at slopes of the volcano, on the other side there were the books that analyze the individual eruptions as a case study of a general theoretical model.
This transition from a traditional narrative scheme to one more scientifically modern, it is represented by the Natale di Pace Compendium manuscript in which, while maintaining a traditional argumentative framework, there is the philosophical need to bring the observed volcanic phenomena back to a single origin, more adherent to the new observations

S16.11 - Presentazione orale

Origins of the islet of Vulcanello (Vulcano, Aeolian Islands): a review of historical sources

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The Vulcanello lava platform along with the three now inactive pyroclastic cones, constitutes the northernmost part of the island of Vulcano (Aeolian Islands). The sandy isthmus that connects the platform to the main island, has emerged from the sea since the 16th century, thanks to the contribution of volcanic ash mainly emitted by the La Fossa crater and transported to the northern coast of Vulcano via the Vallone Palizzi. For centuries prior to the 16th century, Vulcano and Vulcanello were two adjacent, but geographically distinct islands. For a longtime the interpretation of ancient sources dating back to the 2nd-1st centuries BC led scholars to believe that the islet had been built suddenly around 2200 years ago, thus implying its presence, as an autonomous island, in the 1st Christian millennium. However, this account is not verified by the geographical accounts of the time: indeed, the alleged island was not attributed a name, nor was it counted in the inventory of the individual Aeolian Islands, or at least until the dawn of the 2nd millennium. Strabone speaks of the solidification of a mud platform in the body of water between Vulcano and Panarea, which emerged several days after the occurrence of submarine eruptions. Shortly after a delegation was sent by the Senate to carry out propitiatory rites on the island. This event is later confirmed by Tito Livio, he reported the emergence of a new island near the Sicilian coast in the year that Hannibal died (183 BC). Paolo Orosio also reports that in 126 BC, the day after the eruption of Etna, the sea off Lipari began to boil and emitted suffocating gases. The reports of Pliny indicate that other eruptive phenomena occurred in the period between 91 and 88 BC coinciding with the interval of the social wars. Pliny also reports that for a few days Vulcano and Lipari were burned together. Altogether the various testimonies from the classical age are in agreement that the time interval spanning between 183-88 BC was characterized by multiple eruptions, which led to the emergence of land in the stretch of sea between Lipari and Vulcano. Following its construction, the island was probably washed away by the waves, and it remains unclear how long the presence of this island persisted. Analysis of the sources in the period placed at the turn of the year 1000 AD verify that the first name assigned to the islet was Ǵabal ʼal burkân, which in Arabic means volcano mount. This was certainly used to refer to Vulcanello in the work of Al-Idrīsī in the middle of the 12th century, together with Ǵazírat ʼal Burkân, which literally translates as Vulcan island, and this appears for the first time in the middle of 10th century work by ʻAl Mas-ūdi [Amari, 1880]. In 1068 Al Bakri writes that the great volcano is located on two islands north of Sicily. A testimony of December 1184 describes the island of Vulcano and that of Vulcanello, which were both active. The latinizing culture of the time meant that the Arabic name was translated to "Insulam Vulcanelli", as can be seen from an inventory of the church of Lipari-Patti of 1247, which recorded information from its hunting exploitation [Iacolino, 2001]; given the plural nomenclature used, it had to represent an extensive platform with two or more volcanic cones of modest size. The modern name of Bulcanin or Vulcanello was used by the 15th century. Taking into account that an eruption and the emergence of an island certainly occurred in the Aeolian Islands in the classical era, and that traces of this island were subsequently lost, the most probable hypothesis is that it occurred in the same area as Vulcanello, and was subsequently removed by marine abrasion. The remaining shallow water could have presented the structural element necessary to allow the formation of the lava platform and cone n.1, as we know them today, around the year 1000 AD [Arrighi et al., 2006]. The review of historical information relating to the classic age and medieval period, the discovery of new documents, and their comparison with the geological data, lead to hypothesize that the volcanic activity in the area occurred in three main phases: i) a Roman era phase, probably in the 2nd and 1st centuries BC, during which time a first island emerged from the ocean, and was subsequently eroded by the sea (Paleo-Vulcanello); ii) an important medieval phase, that took place in the same area, in the 10-11th century or so, and led to the construction of a stable island (Medieval Vulcanello) with formation of the cones n.1 and n. 2 and the main lava platform; and iii) a Late Medieval-Modern phase in the 15th and 16th centuries which led to the formation of cone n. 3 and the lava flow of Punta del Roveto and Valle dei Mostri. Both historical sources from the classical period and those from the Middle Ages, often report the contemporary eruptive activity at the cone of La Fossa and Vulcanello indicating that the two eruptive systems are fed by a common magmatic system.

S16.12 - Presentazione orale

Resilience and adaptation to volcanoes in Medieval Lipari

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Volcanic activity resumed during medieval times at Lipari following at least 6000 years of quiescence. This phenomenon occurred in a strongly developed social context and was burdened by a demographic crisis that involved the archipelago between the 6th and 11th century AD.
The earthquake that affected Northeastern Sicily and Lipari in the second half of the 4th century AD could represent the beginning of an unstable period in which the Aeolian Islands became a place of exile followed by the abandonment after the terrible Arab incursion in 838. The rare archaeological records relating to the 6th-11th centuries suggest abrupt changes in the population of the islands. Changes in the territorial occupation include the use of living in caves (Vallone Castagno at Salina) and efforts aimed to the water collection and conservation with the excavation of cisterns on rocky plains (Monte at Lipari and Mastrognoli at Salina). In the agricultural plains of the western side of Lipari some settlements have been identified at Piano Greca, Castellaro and Palmeto while seaside villages were located on the coast at Pignataro di Fuori and Valle Muria.
The legend of San Calogero, happened in this phase, tells he make the gushing of the healthy thermal waters. He was sent to Lipari by the Church between 525 and 561 AD, in order to appease the increasingly widespread endogenous phenomena and to bring back them to the nearby island of Vulcano, considered the seat of the underworld according to Christian beliefs. The Early Medieval sources are rich in religious and fantastic references to volcanic events linked to Lipari and Vulcano, testifying the uneasy condition for the human communities. The most famous is the visit of the Anglo-Saxon bishop Willibald in 729 when Monte Pilato eruptive activity in the North-East part of Lipari occurred. We will discuss of the radiometric dating 776 AD [Keller J., 2002] elaborated on charcoals collected from the paleosoil under a basal layer of Monte Pilato pomice. This dating is connect with the stratigraphy of the archaeological site of Contrada Diana where a pumice layer sealed the remains of the late imperial Roman period [Bernabò Brea L., 1988]. The volcanic activity resumption of Lipari-Vulcano complex, includes the eruption of Gran Cratere of Vulcano (Carruggi Formation) and the emerged part of Vulcanello, dated around 1050. Starting from 1083 the Aeolian archipelago was involved in a repopulation program, implemented in 1095 by the Constitutum and organized by the Benedictine Monastery with the annexed S. Bartolomeo Cathedral on the Acropolis. We can assume that from the 11th century the volcanic phenomena, being strictly limited to the northern sector of the island, did not interfere as previously with the anthropic activities. The Monastery will be enlarged in the Norman phase during the first half of the 12th century with the construction of the cloister. New historical documents relating to the 1264, report news of fires and movements of the lands of Lipari [Manni M. and Coltelli M., 2017]. Recent archeomagnetic dates obtained from the lava flow of Rocche Rosse at 1220 Â± 30 AD [Tanguy J.C. et al., 2003] and radiometric dating with fission traces from an obsidian block of the Lami pyroclastic cone at 1243 Â± 190 AD [Bigazzi G. et al.] allow us to associate these events with the last eruption phase of Monte Pilato. This presentation makes in comparison volcanological, archaeological and historical data and presents an updated summary of one of the lesser known phases of the history of the archipelago. The main consequence of the medieval volcanic activity at Lipari caused a clear division of the territory with the population confined in the Southeast quadrant,

protected to the North by Serra and Monte Rosa which represented a natural orographic barrier. Rural activities lasted continuously throughout the western sector of the island, naturally protected from the eruptive centres of Forgia Vecchia and Monte Pilato by Monte Sant'Angelo. The deep transformations carried out by the volcanoes in the Northeast part of Lipari, which was an important mining area for the collection and exploitation of obsidian and pumice since the Neolithic, obliterated any remains of human settlements except for the 20th century, cave di pomice mining, still testified by its embarrassing industrial remains.

S16.13 - Presentazione orale

Born of the Ignimbrite concepts and development of the Rheoignimbrite model (AD 1958-1975)

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The great explosive eruptions that occurred between 19th and 20th centuries (Krakatau, 1883; Mt. Pelee and St. Vincent, 1902; Vesuvius, 1906; Katmai-Novarupta, 1912) produced a fundamental cultural impact on the development of Volcanology as a science. Ignimbrite formation and their emplacement mechanisms was at the base of an international debate, the trace of which in the scientific literature is searched out in this work. Various definitions of pyroclastic products and a new terminology of ignimbritic deposits were tempted and particularly discussed in the framework of the IAV conferences in 1961 at Catania and in 1963 at Tokio. At first, ignimbrite deposits are assimilated to welded tuffs. At the end of 60's of the 20th century, with some exceptions, the definition of nuee ardentes as the emplacement mechanism and of ash-flow tuff as the main deposit entered in the ignimbrite nomenclature. The new attention to explosive volcanism and its deposits of the first half of the 20th century was the context of which has matured the model of rheomorphic ignimbrite introduced by Alfred Rittmann in 1958, and shared by Giorgio Marinelli, to describe the extensive sheet of acidic vitrophyric volcanic rocks of Monte Amiata volcano, that was interpreted as lava flows by all previous authors. Rheomorphic ignimbrites, in the Rittmann model, have characters that strongly differentiate them from normal ignimbrites and that are very similar to what shown by acidic lava flows. This is particularly true for fluidization structures and wrinkles. The Rittmann authoritative assumption inhibited up to present times all subsequent new volcanological interpretation on Monte Amiata acidic lavas. This work deals with the grown and evolution of the ignimbrite concept inside the volcanological literature and on the role that the deposits of Monte Amiata, defined as rheoignimbrites by Rittmann in 1958, played on the improving of the development of the ignimbrite concept, and on the general comprehension of what now we call tephra deposits.

S16.14 - Presentazione orale

Descriptions of Etna eruptions at the turn of the 16th and 17th centuries through the chronicles and drawings of the inedited compendium of Natale di Pace

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The activity of archpriest Natale di Pace (1565-post 1640) of Bronte town, on the lower NW slope of Etna, is temporally framed in a very intense eruptive period the volcano between the second half of the sixteenth and seventeenth centuries. During the seventeenth century, Etna produced the greatest eruptions in historical time, in terms of lava volumes and the highly destructive impact on the territory and the urban fabric. In this important period of the volcano's activity, despite a gradual increase in interest in volcanic phenomena, there are still gaps in the documentary sources and discrepancies as evidenced by recent historiographic studies. In this regard, the observations of the eruptive activity reported in the *"Compendio della Naturale Historia di MonGibello"* by Natale di Pace in 1621 [Scalisi et al., 2019] constitute only a few pages representing inedited descriptions that in few cases add new knowledge to the field of historical studies of Etna's eruptions, although they show numerous inconsistencies on the dates of the events. In particular, the analysis of the compendium confirms that the eruptive period between the 16th and 17th centuries described in contemporary sources remains incomplete. The doubts and uncertainties of the historical documents highlight, once again, the scarce reliability of the use of such sources to reconstruct the eruptive history of the volcanoes in absence of a comparison with geological evidence.

A highly innovative aspect of the compendium, on the other hand, are the illustrations accompanying the manuscript. These are watercolor and gouache drawings, probably realized by the painter Giuseppe di Viti, which illustrate the theory on the origin of volcanic phenomena described in the manuscript. Some of them, of high artistic attractiveness, generically represent the different types of eruptive events that occur on Etna without any reference to specific eruptions described in the compendium. In particular, the author in some drawings summarizes schematically all the eruptive phenomena he observed during the complex and long period of activity that characterized the first twenty years of the seventeenth century, anticipating the same typology of drawings that illustrate the volcanological works from the end of the nineteenth century [Abate & Branca, 2015]. In this context, the watercolor drawings of the Natale di Pace compendium are distinctive in the long iconographic journey that has characterized the illustration of Etna's eruptive phenomena from the sixteenth century onwards.

S16.15 - Poster

Someone walked on the divine mountain: fossil traces and prehistoric paths on the ashes of the Roccamonfina volcano (Central-Southern Italy)

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The Roccamonfina volcano is well-known all over the world for it preserves, among precious naturalistic wealth, also one of the most important human and animal ichnosites in the world dated at about 350.000 years BP.
Hominin and animals (elephant, bear, horse, deer) footprints have been found on top of an ignimbrite deposit (a unit of the Brown Leucitic Tuff dated at about 350.000 y BP), impressed on a high angle and articulated surface up to 80° with an average incline of ~30° along a small valley. The tracks were left very shortly after the emplacement of pyroclastic flows when the material was still plastic and cold enough to permit the passages. The deeply impressed surface was the result of rapid erosional processes along the valley affecting the still soft flow deposit. Further geological and volcanological research will permit a better understanding of the volcanological and palaeoenvironmental evolution of the area at that time and provide more precise information about the ignimbrite deposits when the hominins walked on their sloped surface. This will also contribute to better define Roccamonfina history and evolution.
The footprints preserve all the evidence of clearly aware movements, which they were made both to stabilize the gait and to choose the best route during the descent of a slippery and treacherous slope. In the footprints (sometimes deep, sometimes ephemeral) there are signs of progressive sinking in the still-plastic ground and, sometimes, sudden changes of direction to give appropriate responses to the gravity and to preserve balance. In the same footprints both the displacement rims that describe the footprint contours and the anatomical characteristics typical of the human foot are often clearly visible. One of the three trackways originally found includes in its pattern also the imprint of a long slide, which is flanked by a fossil handprint (the oldest in the world so far known), and the fossil prints of other human anatomical parts (calf, ankle, buttocks, etc..) that cannot be compared to some similar ones elsewhere in the world.
Some other footprints have been found rising the number of the trackmakers, who appear similar to the specimens of Sima de Los Huesos (Atapuerca, Spain) and Ceprano (Italy). They are still under study.
All fossil trackways branch off from an ancient pathway located upstream the steep slope.
The repeated field research and the analyses carried out with increasingly refined techniques, made it possible to detect new ichnological evidence and to document that there are more than three hominids who walked in the same site and that their anatomical characteristics bring them closer to an identification with species similar to the specimens of Sima de Los Huesos

(Atapuerca, Spain) and Ceprano (Italy).
A wide archaeological and ichnological evidence shows that Roccamonfina area could have been crossed over the millennia by an extensive network of logistic connections. It is extremely hard to reconstruct an entire network of prehistoric connections, but in this area, this is an intriguing challenge for its potential to found new sites to be promoted also in the view of an educational and a naturalistic tourism, so transforming the Roccamonfina volcano into a sort of prehistoric Pompeii.

S16.16 - Poster

S17. LANDSCAPES AND GEO-CULTURAL HERITAGE IN VOLCANIC AREAS: A GREAT CHANCE FOR THE MANAGEMENT OF GEOSITES AND THE VOLCANOLOGICAL EDUCATION

Conveners:
Chiara Cardaci (DPC), Rosella Nave (INGV-OV),
Marco Viccaro (UniCt, INGV-OE)

The loss of geological memory of past catastrophes: the case of Pompeii

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In 79 A.D., Vesuvius buried entire cities in just a few days under a blanket of pumice and ash. It was a sudden event, occurred after centuries of inactivity, announced only by earthquakes that were repeated periodically, creating addiction rather than alarm. The vegetation covered the volcanic products and the memory of the disaster was almost lost. The first excavations began in Herculaneum in 1738 and in Pompeii ten years later. Almost intact buildings emerged, with all their contents, with many inhabitants caught in flight. There was still no archeology and every artifact became of royal property. Much was destroyed, given as gifts, thrown away. The arduous journey of site recovery has had important and not always happy stages, accompanied by continuous progress in excavation methods. The mistakes of the past represented the measure of improvement achieved; and so, it will be in the future
Volcanology drew as much from those experiences as it could, aiming to reconstruct the history of an explosive eruption, the first in the world to be described, by Pliny the Younger, fortunately still the only one to have hit a territory so densely inhabited, helpless and unprepared, the one that left its mark on buildings, vegetation, animals and human beings. Without the eruption, Pompeii and Herculaneum would have no reason to exist. Unfortunately, the aim of archeology is that of understanding how lived the ancient Romans, by reconstructing their ancient environment and restoring the city as it was before the catastrophe. The aim of volcanologists is that of understanding how the ancient Romans died and the impact of the eruption on the town. Aim of this work is to illustrate the dramatic loss of volcanological information and how Vesuvius and the Roman settlements could be transformed into a natural super-museum for inspiring not only the public, but also archaeologists and volcanologists in the generations to come.

S17.1 - Presentazione orale

“Naples, history, art and volcanoes”, an underground journey into the heart of the city, on display at the Pietrasanta basilica

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The underground of the city of Naples is a labyrinth of cavities dug into the tuff, forming a mesh of interconnected cisterns and galleries that represent what remains of the ancient water supply network of the Greek and Roman ages. These cavities, and their access passages, allow to descend into the stratigraphy and the volcanological history of the city, going back in time until the epoch of the great eruption of the Neapolitan Yellow Tuff. Many of these cavities have been used for multiple purposes over time, and carry within them the traces of the natural and human history of the city. Some of them were recently recovered and opened to the public, being the ideal sites for discovering the geohistory of Naples.
The Pietrasanta basilica, in the heart of the historical center of the city, is the gate of access to one of the most impressive Naples' underground pathways. It will host until March 2020 the exhibition “Naples - history, art, volcanoes”. The exhibition, curated by the INGV, illustrates the history of the Neapolitan territory, which is the result of the interaction between human and volcanic activity and dynamics, and also inspired a remarkable artistic and cultural production.
The itinerary in the knowledge of the city's underground is realized within a huge cavity, dug into the Neapolitan Yellow Tuff, below the Pietrasanta basilica It starts with a 5 meter long poster that introduces the stratigraphy of the city, showing the deposits of the volcanic eruptions occurred during the past 15,000 years in the Campi Flegrei caldera and at Vesuvius, intercalated with the traces of human frequentation of the area.
Real samples of the rocks that constitute the subsoil of the city are exposed along with the pictures of the site where they were extracted, to allow the visitor to recognize the rocks in their own territory. A video on the eruption of the Neapolitan Yellow Tuff is projected on a striking wall of the cavity for an immersive experience into one of the largest caldera-forming eruption of Campi Flegrei. A giant screen allows to visualize in real time the epicenters of the earthquakes of the Neapolitan volcanic areas, through a system, presented for the first time to the public, that replicates the one present in the surveillance room of the Vesuvius Observatory. Moreover, along the way it is possible to come across a virtual guide, the volcanologist Pietro and his friend Strella (a bat) who discover the subsoil together with the visitor, in the comics drawn by the Comix school.
To complete the exhibition in the Basilica, for the first time on display in Naples, the 15 gouaches of the eighteenth and nineteenth centuries of the Vesuvian Observatory collection. The guoaches, some of which made by famous painters, show the eruptions of the volcano in the past centuries, when it was in a state of semi-persistent activity, different from the current one, with spectacular eruptions. Each gouache is discussed with respect to the eruption represented and its meaning for the definition of the history of the volcano. The path has been integrated with a work on the Vesuvius by the artist Gennaro Regina realized during the X edition of the “Cities on Volcanoes” international congress, held in September this year in Naples, to suggest the deep connection between the art, even modern, the science and the volcano.

S17.2 - Presentazione orale

Geo-cultural importance of the "System of the Salinelle of Mt. Etna" Geosite (Paternò and Belpasso, eastern Sicily) and future perspectives

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The name of Salinelle indicates natural manifestations of emission of fluids, often but not always with formation of mud volcanoes, that occur near the town of Paternò, on the SW slopes of Mt. Etna volcano. Three sites are marked by these natural phenomena: the Salinelle of Capuchins or of the Stadium (Paternò), the Salinelle of the River (Paternò) and Salinelle of Vallone Salato or of San Biagio (Belpasso). These manifestations are characterized by the emission of natural hypersaline water, generally at room temperature, mud, gas and liquid hydrocarbons.
These sites are peculiar, if not unique. Unlike other mud volcanoes around the world, whose driving gas is mostly methane, the gases from the Salinelle mostly come from a deep magmatic source (close to mantle-type). Magmatic gases, probably composed of high-enthalpy brines carrying a lot of heat, produce hydrothermal conditions in a shallow groundwater system and then mix with crustal gas coming a hydrocarbons reservoir after intercepting it through leakage along a regional fault system. The resulting fluids emitted at the surface produce unique landforms, with bland relief due to an abundant liquid component with a low clay fraction (other mud volcanoes in Italy and around the world typically emit fluids highly enriched in mud or clay). Because of the large contribution from deep magmatic gases, the output of fluids at the Salinelle is strongly linked with the deep activity of Mt. Etna. Paroxysmal mud eruptions normally precede new cycles of volcanic activity of Etna by a few to several months. These eruptions are often spectacular and release thermalized waters (Temperature up to about 50°C), which makes the Salinelle interesting also for volcanological and geothermal studies. Another peculiar feature of the Salinelle is that the emission of fluids is continuous, though with much lesser intensity, even during periods without paroxysms, in contrast to what happens at other mud-volcano sites.
The site of the Salinelle of Capuchins (set up with D.A. 581/2015) has been recently considered by the regional government of Sicily for an important redevelopment action, in order to open the site to visitors with all the necessary infrastructures for tourist reception, information and guidance through it ("Linee Guida per la redazione del Piano di Gestione dei Geositi: D.A. 367/GAB, 24.10.2019"). The site will also be provided with up-to-date monitoring systems for acquisition of geochemical and geophysical signals. This will give the scientific community an important opportunity for modeling this exceptional natural system and for understanding how it works.

S17.3 - Presentazione orale

The engineering geological properties of the 1669 lavas from Mount Etna and their use as building stone

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The 1669 eruptive event of Mount Etna is recognized among the largest and most catastrophic historical events ever occurred in Sicily. Later, in 1693, a terrible earthquake destroyed most of the villages and towns located in the south-eastern side of the island.
In the early XVIII century, as the result of a great collective undertaking, several cities were rebuilt according to the Late Baroque style, unique in the world, expressing a high-quality architectonical and artistic achievement. In 2003, for the aforementioned reasons, these cities were included in the UNESCO World Heritage list as Late Baroque towns of the Val di Noto.
It is worth noting that these cities (e.g. Catania, Noto, Siracusa, Ragusa, Modica) testify a close relationship between building stone and geological context, since their reconstruction was carried out by employing only local stone.
In particular, the 1669 lavas were extensively used for construction and restoration purposes and they are still quarried for the production of high-quality material to be employed for engineering geological works. Their relevance increased in 2013, when UNESCO defined Mount Etna as one of the world most active and iconic volcanoes, including it in the world heritage list. Etna lavas are employed as paving material for roads and load-bearing elements for local construction as well as for sculptures and coating for architectural items; some quarries produce also aggregates for bituminous conglomerate and strong, fine concrete by crashing the rock. It is self-evident that the detailed characterization of such rock type, from both the physical-mechanical and textural points of view, is an essential practice, even preparatory for its employment.
To this purpose, the present contribution provides a focus on the laboratory investigation of these 1669 lava rocks, which underwent petrographic, physical, mechanical and seismic analyses. Results showed that two main varieties of lava rocks are mined, distinguished in massive and vesicular rock types. Interesting statistical correlations allowed understanding the mutual dependence of the main engineering geological parameters, highlighting how porosity, through both vesicles and microcracks, plays a leading role from the engineering geological point of view. Achieved results provide a scientific casuistry on this topic and are a reliable reference for studies on similar rock types worldwide, since lavas are among the most used rock materials in the engineering geological practice.

S17.4 - Presentazione orale

Characterization and enhancement of the Geosites and the new geovolcanological paths of the Parco Nazionale dell'Isola di Pantelleria (Strait of Sicily)

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The island of Pantelleria is located in the Sicily Channel Rift Zone (SCRZ) and represents the emerged tip of an underwater volcano complex with 72% lying below sea level, down to a depth of about 1200 m. Its origin is linked to the Pantelleria graben, one of the three main tectonic depressions of the NW-SE trending extensional area in the SCRZ. The rifting process has been active since the Late Miocene, accompanied by widespread volcanic activity mainly concentrated on the islands of Pantelleria and Linosa and the Bannock Seamount. The volcanic activity of Pantelleria started at least 320 ka before present (BP) and was characterized by large explosive events, sometimes followed by caldera collapses, alternating with mild eruptions. The last calderic collapse occurred 44-50 ka BP. The last episode of eruptive activity, occurring in 1891, 5 Km NW offshore North of Pantelleria, showed that the volcanic activity is still present in the submerged part of the island.
To date, the volcanism of Pantelleria is still on-going with the presence of a natural spa, thermal springs, fumaroles, that are located along the main tectonic structures. Currently, some of these places are officially recognized as Geosites and in particular "Favara Grande", "Fumarole della Vecchia Caserma", "Monte Gibele", and "Specchio di Venere" are protected by the Parco Nazionale dell'Isola di Pantelleria.
The island's trail network comprises as many as 19 paths, for a total of almost 100 km, with different themes, ranging from the naturalistic to the geological and the historical to the rural, and varying in the type of route, namely point-to-point or circular, as well as in length and height. This work aims to describe the Geosites of Pantelleria and highlight the geovolcanological characteristics of the island's trails.

S17.5 - Poster

Education and geotourism at the Etna volcano: the example of Mount Grosso - Mount Gemmellaro path

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Recently, on the Etnean territory, local and national associations have marked several trails; however, it is worth noting that, up to now, no didactical geological paths have been proposed. The present contribution focuses on the geological aspects of a path in the southern flank of Mount Etna, in terms of effectiveness for teaching geosciences, and aims to revise and propose it in a new guise as a geo-trail. The proposed path is named after the geologist-naturalist Carlo Gemmellaro (1787-1866) and develops for ~ 3 km in length at an altitude of about 1300 m a.s.l. Along this itinerary, it is possible to admire several lava flows relative to eruptions that took place on the second half of the XIX century up to the beginning of the present century, thus shaping the landscape. The geo-trail is peculiar since, in a quite short distance, it permits geotourists to observe and get familiar with various volcanic structures such as hornitos, pyroclastic cones, lava flows and lava channels as well as several volcanic rock types. At the same time, the geo-trail constitutes a tool students' geo-education through laboratory activities in the field, promoting the development of environmental awareness in the students. Finally, the path also permits teachers a multidisciplinary approach, since the XIX century eruptions are well documented by detailed historical and cultural reports.

S17.6 - Poster

Micro erosion rates on volcanic rocks at Ustica (Palermo, Italy)

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Micro erosion meters (MEMs), following High and Hanna [1970], and traversing micro erosion meters (TMEMs), following Trudgill et al. [1981], allow evaluating the rock lowering rates. They have been widely used on carbonate rocks in different environments, such as coasts, caves, buildings, but rarely on volcanics.
We discuss preliminary data collected from May 2016 to June 2017 on the island of Ustica, which is composed of Middle Pleistocene to Late Pleistocene volcanic rocks. The island is 8.6 km^2 and the maximum elevation is 248 m a.s.l.
The installation of micro erosion meter stations and data organization were carried out following the method suggested by Furlani et al. [2009] for the Trieste karst area.
We placed 12 stations on volcanic rocks in 7 sites on the island of Ustica to measure the lowering rates on such rocks, ranging from 20 to 200 m a.s.l. Three samples were collected around the island and located at the site of Rocca della Falconiera, at 150 m a.s.l. The studied rocks are compact lavas and tuffs of basalt or trachybasalt composition.
The analysis of three years of measurements highlighted means lowering rates ranging from 0.001 mm/a to 0.025 mm/a. All the iron nails used in the project are oxidized after only one year of measurements, suggesting to use titanium nails also for the sites located at highest elevations, since all the island is affected by spray weathering.

S17.7 - Poster

Stromboli 2019 - The summer camp after the eruption

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Stromboli is a small town on a small volcanic island that host thousands of tourists during summer times, many of whom arrive attracted by the amazing show of a persistent and apparently harmless volcanic activity. Stromboli also hosts a small number of very active residents, who founded various cultural associations committed to improve the life on the island and to protect its environment. One of these associations gathers the civil protection volunteers (Volontari Isola di Stromboli), who, among other kinds of activities, are in charge of the organisation of a kid's summer camp held within the national campaign "I am Civil Protection too".
Activities held at the camp are meant to educate young residents about the natural hazards on the island, increasing their awareness while strengthening mutual connections and favouring team building.
In this framework, INGV researchers have often been guests of the camp, to discuss topics pertaining to the volcanic activity. The summer camp in 2019 was organised during the spring, but was held at the beginning of September, after the two paroxysmal eruptions that shook the island in July and August.
In this contribution we will describe the approach we took to reach out to the kids and work with them to gain a better knowledge of their island and of the different hazards they face.
A first phase was dedicated to know each other, through a simple game that allowed them to propose questions and answers related to volcanic activity. Then we proposed the individual construction of an active volcanic conduit, powered by a rubber band, where each kid was able to work alone on her/his own conduit. Finally, we all contributed to the construction of a model of the island. One of the conduits was then used to perform repeated ballistic ejections and observe the distribution of deposits, testing the behaviour of different materials, and assessing the role of ejecta speed and conduit inclination on the impacted area.
We will discuss the role of each of these three phases (questions and answers; individual construction, and teamwork) and presents a few conclusions and suggestions for future activities.

S17.8 - Poster

The "Salinelle of Mt. Etna" Geosite: thermo-physical and geochemical monitoring of hydrothermal fluids, aimed at understanding both their geothermal potential and their possible correlations with Mt. Etna activity

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Knowledge of hydrothermal fluid emissions can provide detailed information about processes operating at different depths, such as geothermal fluids upwelling with their own characteristics' variable over times. In particular, at the "Salinelle of Mt. Etna Geosite (Paternò and Belpasso, Eastern Sicily), natural emissions of fluids have been continuously occurring for at least 12 ka. Their main peculiarity consists of a fluid phase made of salty water, mud, gas and liquid hydrocarbons originated from an admixture of magmatic and hydrothermal gas, leading to the formation of mud volcanoes with the most peculiar morphologies [Giammanco et al., 2016].
Our study mainly focused on the thermo-physical and geochemical monitoring of the hydrothermal fluids emissions of the more active site known as "Salinelle dei Cappuccini", in the Western part of the city of Paterno'. In order to compare this activity with that of other hydrothermal vents in the same area, the "Salinelle del Fiume" (Paternò) and the "Salinelle di San Biagio" (Belpasso) Geosites were also investigated. In particular, field and laboratory analyses were conducted over more than one-year monitoring. They consisted on: i) continuous water temperature monitoring, using sophisticated thermal sensors (accuracy of 0.1°C) immersed in the pooling waters; ii) InfraRed Thermography (IRT) measures, using a thermal camera (resolution of 320 x 240 pixel) [Chicco et al., 2019]; iii) Thermal Conductivity properties determinations, through a commercial device consisting of a needle probe directly inserted in the investigated material during both field and lab activities; iv) mineralogical compositions through X-Ray diffraction; v) geochemical analysis, focusing on Electrolytic Conductivity, Salinity, CO_2 and Rn determinations, using specific portable field. This was followed by mud/water sampling for VOC (Volatile Organic Content), Alkalinity, Electrical Conductivity, major species in solution and oxygen lab determinations. A further study centered on seismic parameters evaluation such as the Magnitude and its relationship with the frequency of seismic events all around the Mt. Etna area. This revealed useful in verifying how seismic activity linked to volcanic events can affect mud volcanoes activity. Obtained results highlighted a direct correlation between Temperature and Thermal Conductivity data as well as between Electrical Potential and Electrical Conductivity, without any link with CO_2 and Rn contents. Daily temperatures showed a constant trend characterized by higher values (up to 35°C and more) within the first monitoring period, followed by a strong decrease (down to 9°C) and then a new gradual increase over the following months. This large variation seems to be linked to magmatic processes occurring at depth below Mt. Etna, likely related to early stages of magma upraise towards the surface. In particular, the higher the frequency of seismic events and then the higher the daily energy released, the higher temperature variations observed. This correlation could be explained by the ascent of new gas-rich magma from the deepest magma reservoir of Mt. Etna, producing crustal fracturing along

its path. Large release of high-enthalpy fluids from the new ascending magma enhanced gas-water interaction in shallow aquifers crossed by major faults acting as gas escape pathways through the flanks of Mt. Etna, with consequent modification of the geochemical and temperature characteristics of the fluids issuing at the surface in the mud-pools and gas vents of the Salinelle.
Understanding how these fluids blend and what is their relationship with Mt. Etna volcanic activity can be of great importance in forecasting new eruptive cycles of the volcano.

S17.9 - Poster

The geological section of the Villa Arbusto archaeological museum at Lacco Ameno (Ischia, Naples)

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A room in the Archaeological Museum of Villa Arbusto (Lacco Ameno, Ischia) was set up to house the collection of rocks and fossils collected by the renowned archaeologist Giorgio Buchner during his excavation activity on the Island of Ischia. The collection is witness to a long multidisciplinary research activity that saw archaeological studies at the center of volcanological, pedological and palaeoenvironmental researches aimed at reconstructing the archaeological contexts in the complex geological dynamics of the island.
During the different phases of colonization recorded on the island volcanoes were active and produced explosive and effusive eruptions, accompanied by a strong geological dynamic that included earthquakes, landslides (even gigantic ones), rapid ground uplift and strong hydrothermal activity.
The samples on display "tell" the evolution of the island and its dynamics in four windows and a chest of drawers, where there is an exposition of the products of the various eruptions, from the oldest to the most recent, sedimentary rocks and the collection of fossils and microfossils found in marine sediments, displaced at variable altitudes by the rapid volcano-tectonic deformations that characterize the island.
A series of panels and monitors accompany the visitor along a path that, starting from the geological evolution of the island, passes through the relationship between humans and the volcano, the main volcanic phenomena and the reconstruction of an archaeological excavation of exceptional value, where it is possible to see the strong interaction between primary and secondary volcanic phenomena and a human settlement of the first Greek colony in the west: Pithecusae.
The exhibition was designed with the purpose of educating the visitors and the local population about the natural history of the island and its volcanoes, and their impact on the human life through time
The room has been set up by the Naples section of INGV Osservatorio Vesuviano in collaboration with the Archaeological Superintence and the DISTAR of the University of Naples Federico II. This activity is included in the framework of information and scientific dissemination programs, carried out by INGV and aimed at improving risk mitigation by increasing awareness and developing a culture of coexistence with natural hazards.

S17.10 - Poster

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