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Nicolosi (Catania) 29 | 31 Ottobre 2014

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Ornella Cocina e Eugenio Nicotra editors

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

Associazione Italiana di Vulcanologia

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Etna 2 luglio 1942
(Fondo fotografico Gaetano Ponte Archivio Fotografico Toscano Prato)

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Indice

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SESSION 1

Volcano Geology and Structure

Seismological Constraints on Deep Seismicity Occurring in the Northwestern Flank of Mt. Etna

Salvatore Alparone, Graziella Barberi, Giuseppe Di Grazia, Ferruccio Ferrari, Elisabetta Giampiccolo, Vincenza Maiolino, Antonino Mostaccio, Carla Musumeci, Luciano Scarfì, Antonio Scaltrito, Andrea Ursino

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The occurrence of seismic events located in the basement of a volcanic structure is usually associated with the variation of the volcanic activity. At Mt. Etna, it has been observed that during the recharging phases a deeper seismicity (up to 15–20 km) characterizes the southern and western sectors of the volcano [Patanè et al., 2004; Bonaccorso et al., 2004].

On December 2009 an intense seismic sequence was recorded in the northwestern flank of Mt. Etna. It was characterized by more than 400 events with maximum magnitude 4.8 and located at depth between 20 and 30 km. About 50% of the earthquakes occurred in the first 24 hours of the sequence which, in terms of strain release, is the strongest in the last ten years, except those occurring during sin-eruptive times. A preliminary time-space analysis of the sequence evidenced that earthquakes are distributed along two main trends, NE-SW and E-W oriented and foci are located at about 20-25 km b.s.l.. Moreover, a northward migration of the epicenters and a deepening of the foci with time has been observed. Fault plane solutions of most of the earthquakes show dominantly strike-slip rupture mechanisms with, in several cases, a remarkable normal component. In the northern sector reverse dip-slip mechanisms are mainly observed. P-axes directions are mostly oriented along a NNW-SSE direction. Afterwards, other important swarms in the same area have been recorded during 2010, 2011 and 2012. In order to detect any possible indication of seismogenic activity in this area linked to the volcano dynamics, we analyzed the distribution and kinematics of the deep seismicity recorded in the northern and northwestern sector of the volcano from 2000 to 2012. A total of 805 earthquakes deeper than 15 km were used as data source for this study. Specifically, we re-located the events by using the tomoDDPS code [Zhang et al., 2009] and the 3D velocity model by Alparone et al. [2012] and calculated the FPSs by using the FPFIT algorithm [Reasenberg and Oppenheimer, 1985] that were used for stress tensor inversion. A spatio-temporal analysis of seismic strain releases was carried out considering different portions of the focal volume. We found well-defined periods during which the different sectors identified were active at the same time. We also applied a cross-correlation analysis in order to evaluate the similarity of waveforms useful to identify earthquakes families. Finally, on a selected subset of events we calculated the source parameters (seismic moment, source radius, and stress drop).

Results do not show any possible correlation of the deep seismicity recorded in the northern and northwestern sectors of Mt. Etna with volcanic activity. Conversely, the data presented here seem to support the activation of regional tectonic structures due to the compressive regime of the Apennine-Maghrebian Chain.

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Dynamics of Vulcano Island Investigated by Long-Term (40 years) Geophysical Data

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Vulcano island is a composite volcanic edifice located in the south-central sector of the Aeolian Archipelago and it is an important tourist destination. Historic activity has been characterized by frequent transitions from phereatomagmatic to minor magmatic activity. The last eruption in 1888-90 was characterized by energetic explosive pulses and defines the "vulcanian" type of activity. Since then, volcanic activity has taken the form of fumarolic emanations of variable intensity and temperature, mainly concentrated at "La Fossa" crater, with maximum temperatures ranging between 200° and 300° C; temperature increases and changes in the gas chemistry, were often observed. The most recent episode began in the 80's when fumarole temperature progressively increased to 690°C in May 1993. Vulcano is active and this favoured monitoring and research studies, in particular focused on the most recent structures.

In the frame of DPC-INGV "V3" project, we investigate the Vulcano dynamics through ca. 40 years of ground deformation and seismicity data collected by the discrete and continuous INGV monitoring networks. We considered levelling, GPS, EDM, seismic and tilt data. EDM and levelling measurements began in the middle 1970s and since the late 1990s the EDM benchmarks have been measurered using GPS.

We observed three scales of ground deformation: the first one seems to be linked to the regional tectonics, with a general transpressive kinematics; the second one affects the northern half of the island and could be related to the caldera dynamics; the third one affects only the cone of La Fossa. Regional tectonic stress seems to play an important role in the transition of the volcanic system from a phase of stability to a phase of unrest, inducing the heating and the expansion of shallow hydrothermal fluids. Ground deformation at Vulcano may be linked to the geothermal system rather than magmatic sources.

Present Day Kinematics of the Aeolian Islands and the Case of Lipari

Marco Anzidei[1], Alessandro Bonforte[2], Alessandro Bosman[3], Valentina Bruno[2], Roberto Carluccio[4], Cosmo Carmisciano[4], Daniele Casalbore[5], Massimo Chiappini[4], Francesco Latino Chiocci[3], Francesca D'Ajello Caracciolo[4], Alessandra Esposito[1], Massimo Fabris[6], Maria Marsella[7], Mario Mattia[2], Filippo Muccini[4], Iacopo Nicolosi[4], Grazia Pietrantonio[1], Vincenzo Sepe[1], Riccardo Vagni[4]

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The active volcanic arc of the Aeolian islands is located between the Southern Tyrrhenian Sea back arc basin (Marsili basin) and the Calabrian Arc, an orogenic belt affected by a Late Quaternary extensional tectonics and uplift. This region is still undergoing to shallow and deep seismicity up to 550 km and active volcanism due to the subduction extensional strain and heat flow related to the slab detachment beneath the Calabrian Arc.

In this geodynamic framework, the current crustal deformations detected at the ground surface by continuous and episodic GPS data collected in the archipelago and its surroundings in the time span 1996-2012, reflect both the behavior of the single volcanic islands and the regional tectonics of this complex region. Particularly, we will focus on the current vertical component of land motion that indicate a diffuse subsidence that is in contrast with uplifting Quaternary geological data. We will discuss data for Panarea and Lipari islands for which we have integrated geodetic, archeological, high resolution multibeam bathymetry, aerial photogrammetry, and sea level change predictions, to tentatively interpret the recent subsidence rates. Particularly, GPS data show that part of Lipari is rapidly subsiding at velocities >10 mm/yr, which is the highest value among the Aeolian island. GPS results are in agreement with independent observations that indicate a continuous subsidence with rates at ~ 8 mm/yr since the last 2200 years B.P., as suggested by archaeological and historical data. The current geodetic strain and velocity field for the Aeolian archipelago will be discussed, as well as the GPS data archive that will be soon available for the scientific community.
Finally, we will show some preliminary results on the ongoing activities at Lipari Island. These include the production of high resolution marine and terrestrial DTMs by means of multibeam bathymetry and aerial photogrammetry. The latter also performed locally by drone surveys. The goal is to provide a flooding scenario for Lipari Island, due to the combined effect of continuous land subsidence and sea level rise that will cause a wide submersion of the coast by the year 2100 and represent a significant hazard within an urbanized coastal area.

New Insights in the Geodynamics of the Lipari-Vulcano Area (Aeolian Archipelago, southern Italy) from Geological, Geodetic and Seismological Data

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Geological, geodetic and seismological data have been analyzed in order to frame the Lipari-Vulcano com-plex (Aeolian archipelago, southern Italy) into the geodynamic context of the southeastern Tyrrhenian Sea. It is located at the northern end of a major NNW–SSE trending right-lateral strike-slip fault system named "Aeolian-Tindari-Letojanni" which has been interpreted as a lithospheric discontinuity extending from the Aeolian Islands to the Ionian coast of Sicily and separating two different tectonic domains: a contractional one to the west and an extensional one to the north-east. Structural field data consist of structural measurements performed on well-exposed fault planes and fractures. The mesostructures are mostly represented by NW-SE striking normal faults with a dextral-oblique component of motion. Minor structures are represented by N-S oriented joints and tension gashes widespread over the whole analyzed area and particularly along fumarolized sectors. The analyzed seismological dataset (from 1994 to 2013) is based on earthquakes with magnitude ranging between 1.0 and 4.8. The hypocenter distribution depicts two major alignments corresponding to the NNW-SSE trending Aeolian-Tindari-Letojanni fault system and to the WNW-ESE oriented Sisifo-Alicudi fault system. GPS data analysis displays 3.0 mm/yr of active shortening between the two islands, with a maximum shortening rate of about $1.0 \cdot 10^{-13}$ s^{-1}, between La Fossa Caldera and south of Vulcanello. This region is bounded to the north by an area where the maximum values of shear strain rates, of about $0.7 \cdot 10^{-13}$ s^{-1} are observed. This major change occurs in the area south of Vulcanello that is also characterized by a transition in the way of the vertical axis rotation. Moreover, both the islands show a clear subsidence process, as suggested by negative vertical velocities of all GPS stations which exhibit a decrease from about 15 to 7 mm/yr from north to south. New data suggest that the current kinematics of the Lipari-Vulcano complex can be framed in the tectonic context of the eastward migrating Sisifo-Alicudi fault system. This is dominated by transpressive tectonics in which contractional and minor extensional structures can coexist with strike-slip motion.
This work has been published on Journal of Geodynamics (http://dx.DOI.org/10.1016/j.jog.2014.07.003).

A Volcano Grows Before Our Eyes: The New Southeast Crater of Etna, 2011-2014

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Following its birth and initial growth in 2011-2012 [Behncke et al., 2014], the New Southeast Crater (NSEC) at the summit of Mount Etna produced frequent episodes of lava fountaining and/or Strombolian activity in 2013-2014, and its cone continued to grow at unprecedented rates. Many of the episodes were of rather brief duration and violently explosive, producing mostly pyroclastic material and minor volumes of lava. Since mid-December 2013, the episodes were characterized by moderate to violent Strombolian activity without producing sustained lava fountains, and by emission of more voluminous lava flows. Some of these episodes produced the longest lava flows of the entire eruptive period of the NSEC initiated in 2011, about 4.5 km long.

Many of the eruptive episodes in 2013 showed complexities not seen during the NSEC activity in 2011-2012, with the opening of eruptive vents in numerous locations on the flanks and at the base of the cone, delivering lava flows in all directions except west (due to the presence of the old Southeast Crater cone). In October-November 2013, lava flows extended for the first time to a significant distance down the upper south flank of the volcano, reaching a distance of 2.6 km from the NSEC. The long-lived activity of January-April 2014 was characterized by lava emission from vents on the lower eastern flank of the cone, accompanied by frequent collapse events on the unstable slope. The largest of these events, on 11 February 2014, produced a fast-moving, ground-hugging, hot (>300°C) avalanche that advanced more than 2 km to the bottom of the Valle del Bove in less than a minute. This event represented a hazard at Etna restricted to the upper flanks of the volcano.

Like in the previous years, the evolution of the NSEC cone was documented by repeated GPS surveys carried out both from a distance and on the cone itself, and by the acquisition of comparison photographs. From these surveys the highest point of the NSEC results to have grown from 190 m (January 2013) to ~320 m (August 2014) above the pre-cone surface, and its volume more than doubled to ~50 x 10^6 m^3, representing nearly half of the total (bulk) volume of the volcanic products including pyroclastic fallout erupted in 2011-2014, which is 100 x 10^6 m^3 (about 70 x 10^6 m^3 dense-rock equivalent). While the Northeast Crater, at 3330 m, remains the highest point on Etna, the NSEC – if it continues to erupt the same way as it has done in the past few years – may soon become the new summit of the volcano.

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Discovery of Etna Pumice Fall Deposits in the Nebrodi Mountains, NE Sicily

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The Late Glacial explosive activity of Etna has been characterised by Plinian eruptions that produced four pumice fall deposits [unit D of Coltelli et al., 2000] and the Biancavilla ignimbrite. These deposits are considered the products of the final activity of the Ellittico volcano formed between 18,533-18,818 cal yrs BP [Coltelli et al., 2000] and 16,965-17,670 cal yrs BP [Siani et al., 2001]. Typical localities of the distal pumice fall outcrops are Giarre and Acireale areas (E lower flank), Biancavilla for the ignimbrite flow (lower SW flank) [Coltelli et al., 2000]. Pumice falls beds form two separate couplets in Giarre and Acireale areas and on the basis of lithofacies and thickness the reconstructed areal dispersal is south-eastward for the Acireale tephra (D1b and D2b) and eastward for the Giarre tephra (D2a). The definition of the areal dispersal has not been possible for the oldest D1a tephra owing to its limited exposures and thickness in Giarre area [Coltelli et al., 2000].

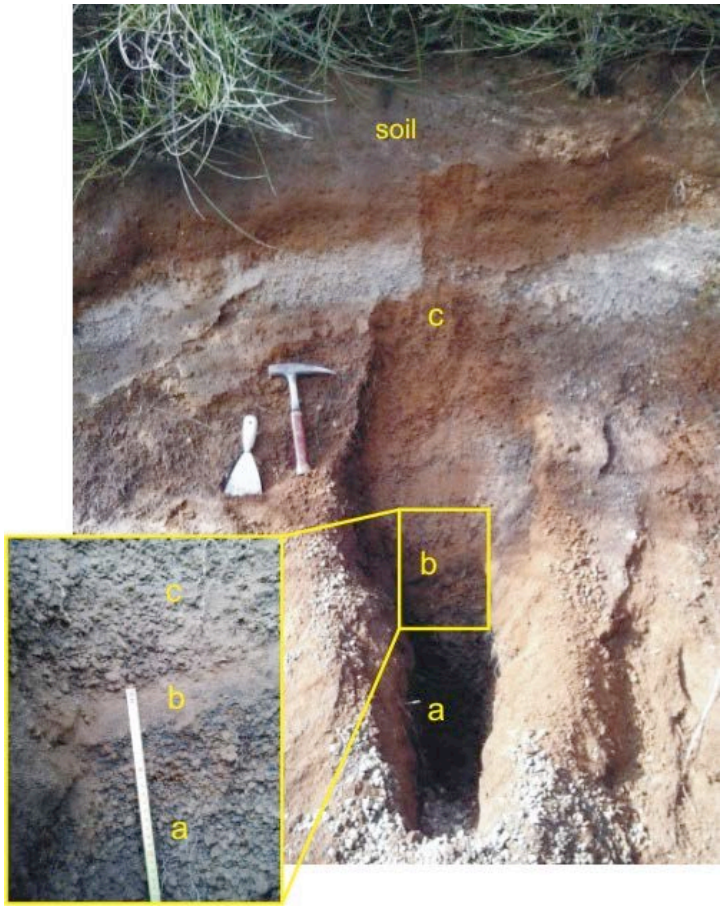

Figure 1. Composite image of the main section at Polverello locality. (a) pumice fall layer, (b) ash layer and (c) pumice fall layer passing upward to soil.

A recent study on proximal-distal tephra correlations and synchronisation of Mediterranean archives have outlined the importance of unit D tephra layers as chronostratigraphical tool [Albert et al., 2013] and has raised issues concerning their correlation with the distal counterparts recovered in marine and lacustrine sediments in different sector of the Mediterranean region (e.g. Lago di Mezzano, Lazio; Lago Grande di

Monticchio, Basilicata; Adriatic Sea; Ionian Sea; Bannock Basin; Haua Fteah, Libya) . Distal tephra glass chemistries and chronological constraints indicate a complex series of dispersals from Etna spanning the last glacial-interglacial transition [Albert et al., 2013]. Given that, it seems evident that a better knowledge of the areal dispersal of the individual tephra layer belonging to unit D is needed, especially in those areas not yet investigated.

We present new stratigraphic and geochemical data on pumice deposits recovered between Floresta and Montalbano Elicona towns in the Nebrodi Mountains. The pumice deposits crop out at about 1300 m of elevation at Polverello locality, 26 km north of Etna summit. In particular in this area, we have measured a well preserved pumice fall deposit 144 cm-thick (Fig. 1) and several 20-30 cm-thick pumice fall deposits, showing erosion surfaces at the top. These pyroclastic deposits rest on the sedimentary terrains of the Appennine-Maghrebian Chain that are formed by the Floresta calcarenites and the sandstones and marly clays of Capo D'Orlando Flysch.

The main section at Polverello locality is formed at the base of a 47 cm-thick massive, well-sorted and clast supported pumice lapilli, up to 4.5 cm in size, layer (Fig. 1). Pumice are poorly vesciculated, black to light-gray in color and covered by a reddish film of alteration. They show variable porphyricity with crystals of plagioclase, clinopyroxene, amphibole, olivine, apatite and oxide. Occasionally lava lithics are also present. The deposit continues with an incoherent ash layer, 5 cm-thick, from gray to reddish in color that is partially weathered showing a film of clay alteration (Fig. 1). The top consists of a 88 cm-thick massive layer, well-sorted and clast supported formed by pumiceous lapilli up to 3 cm in size. The pumice clasts are poorly vesciculated, black to gray-yellowish in color and covered by a reddish film of alteration. They show variable porphyricity with crystals of plagioclase, clinopyroxene, amphibole, olivine, apatite and oxide. Occasionally lava lithics are also present. Toward the top of this layer the grainsize of the pumices decrease and the deposits is weathered by a reddish clay matrix percolating from the overlying 0.5 to 1.5 m-thick soil (Fig. 1).

Petrography and alkaline affinity composition of Nebrobi tephra indicated they were erupted by Etna volcano ruling out the origin from Aeolian Islands that have calcalkaline compositions. On the basis of these preliminary data, we tentatively correlate these pumice deposits with those of unit D of Coltelli et al. [2000] and more likely with D1a layer. More accurate geochemical analyses (e.g. trace elements) will provide further information for unequivocally discriminating the deposit.

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The Geology of the II Century AD Amphitheatre Area of Catania (Italy)

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Among the ancient monuments of Catania, the amphitheatre may be considered the most important testimony of the Roman phase of the city. With its longest axis of 125 m, oriented from north-north-west to south-south-east and shortest axis of 105 m, oriented from north-north-east to south-south-west, it had a cavea of 14 steps, divided into three orders, service walkways or ambulacra to the terraces. It had a capacity of approximately 15.000 seated spectators on the terraces and roughly twice as many standing.

The Roman amphitheatre, which was originally built in a peripheral area of Catania, now is located immediately north of the historic center, at the Stesicoro Square. The visible remains of the walls have been excavated in the early 1900s, whereas the remaining parts of the monument are located beneath the eighteenth and nineteenth century buildings that superimpose the amphitheater in western and northern sectors.

The large discrepancies among the geological reconstructions of the urban area of Catania performed stating from the earliest study of Sciuto Patti [1872] are related to distinct aspects such as the absence of: i) radiometric dating of the volcanic products; ii) the critical analyses of the historical sources; iii) the comparison with the archaeological data. In particular, in the previous geological reconstruct a lava flow attributed to the 252 AD through the historical sources impacted and destroyed a limited portion of the north-western sector of the Roman amphitheatre.

We have performed a detailed geological investigation of the Roman amphitheatre area using surface and boreholes data that have been integrated by the petrographic and mineralogical characterization of the volcanic rocks together with radio-isotopic dating. This new geological reconstruction was compared with the archaeological data of the urban district of Catania with the aim of defining the historical eruptions that affected this highly populated area since its urbanization through a multidisciplinary approach. The analyses of the data evidenced that a limited portion of the northern sector of the amphitheatre rests on the sedimentary terrains, conversely the main part of the monument is built on two prehistoric lava flows corresponding to the Barriera del Bosco and Larmisi lava flows of Branca et al. [2011]. The stratigraphy reconstruction evidenced that the area of the building of the monument was bounded to the east and west by anthropogenic morphological scarps that represent the quarry faces for extraction of lava material.

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Holocene Vertical Deformation along the Coastal Sector of Mt. Etna Volcano (eastern Sicily, Italy): Implications on the Time-Space Constrains of the Volcano Lateral Sliding

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A detailed survey of morphological and biological markers of paleo-shorelines has been carried out along the coastal sector of Mt. Etna volcano (eastern Sicily, Italy), in order to better define causes and timing of vertical deformation. We have mapped markers of raised Holocene shorelines, which are represented by beach rocks, wave-cut platforms, balanid, vermetid and algal rims. The timing of coastal uplift has been determined by radiocarbon dating of shells collected from the raised paleo-shorelines and, to correctly assess the total amount of tectonic uplift of the coast during the Late Holocene, we have compared the elevation-age data of sampled shells to the local curve of Holocene sea-level rise. Taking into account the nominal elevation of the associated paleo-shorelines, an uplift rate of 2.5-3.0 mm/yr has been estimated for the last 6-7 ka. This general process of uplifting is only locally interrupted by subsidence related to flank sliding of the volcanic edifice, measured at docks and other manmade structures, and by acceleration along the hinge of an active anticline and at the footwall of an active fault. Based on this new data we suggest more precise time-space constraints for the dynamics of the lower eastern flank of Mt. Etna volcano.
This work has been recently published on the Journal of Geodynamics (DOI: org/10.1016/j.jog.2014.07.006).

Borehole Stress Measurement at Campi Flegrei Caldera: Insight into Unrest Dynamic

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A first in situ measurement of stress field in the active volcanic caldera of Campi Flegrei has been done as part of the Campi Flegrei Deep Drilling Project (CFDDP). A standard Leak-Off Test allows us to evaluate the magnitude of the minimum and maximum principal stress within the pilot well at a depth of 501m. This measurement is essential to evaluate the possible rate of seismicity during the ongoing unrest which started in 2005 and the potential for major crustal failure. Furthermore, taking into account the previous episodes of unrests, occurred in 1969-72 and 1982-84, we show that only minor relaxation of stress occurred since present time and that successive episodes of uplift could increase the potential for seismic swarm and eruption.

The Oceanographic Cruise TOMO-ETNA on R/V Galatea

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Between June 25 to July 3 2014 a multidisciplinary oceanographic cruise focused on the acquisition of geophysical data was carried out offshore Etna volcano and Aeolian Islands. The cruise was performed using the catamaran R/V Galatea by Italian Navy and was conducted as part of the project MED-SUV "MEDiterranean SUpersite Volcanoes", which main objective is to perform an high resolution seismic tomography beneath Mt. Etna and Aeolian volcanoes by using active and passive seismic data.

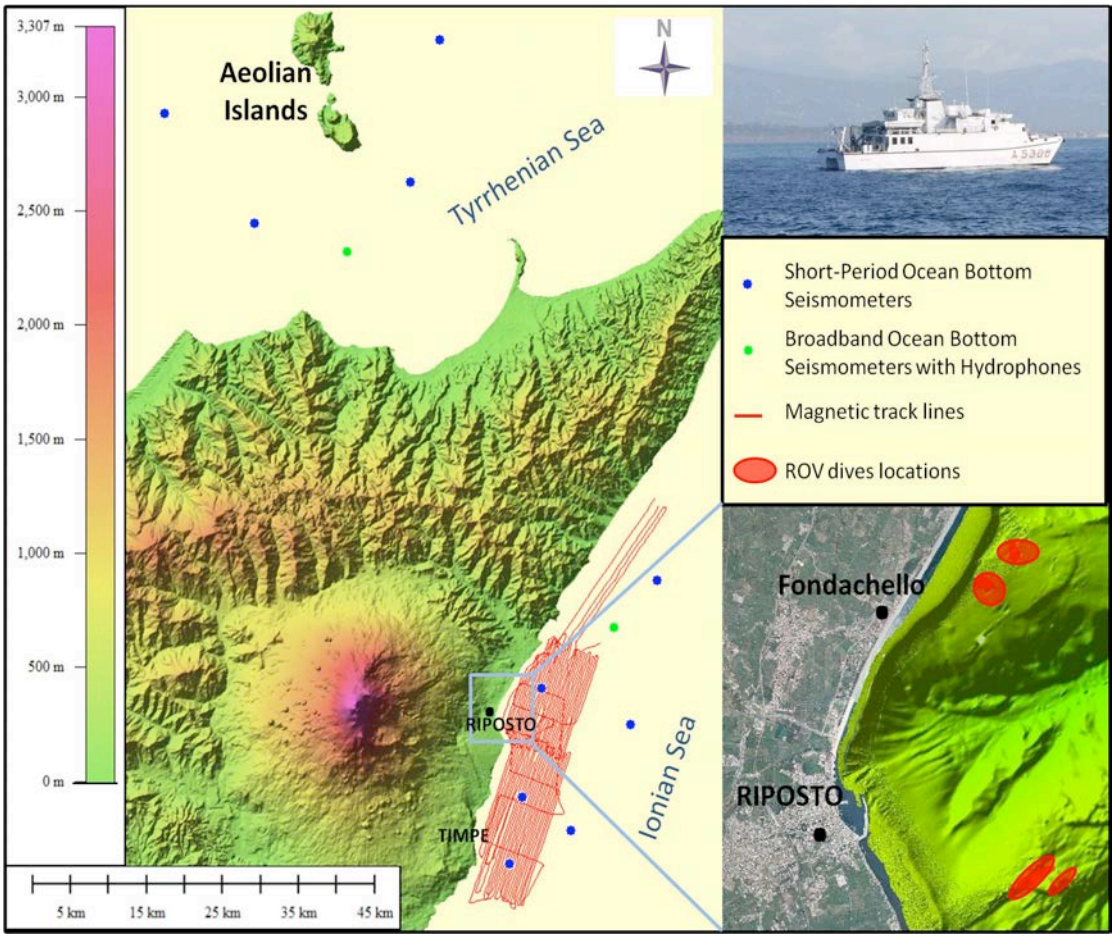

Figure 1. The scientific activities performed using the catamaran R/V Galatea (top right).

The Tomo-Etna experiment was performed through active seismic signals generated by airgun on the R/V Sarmiento de Gamboa (supplied by Eurofleet consortium and CSIC - Consejo Superior de Investigaciones Científicas) and recorded by seismic stations located, both onland and offshore, around Etna volcano and Aeolian Islands; multichannel seismic lines were also acquired in the Ionian sea using a 3 km long streamer with 240 channels.

To better define the main geological and structural features of the area three different scientific activities were performed by researchers of INGV (Istituto Nazionale di Geofisica e Vulcanologia) on the R/V Galatea: OBSs (Ocean Bottom Seismometers) deploying, magnetic survey and ROV (Remotely Operated Vehicle) dives.

A total number of 12 OBSs were deployed either in Ionian (7) and Tyrrhenian seas (5): 10 of them are Short-Period Ocean Bottom Seismometers (OBSSP), the other 2 are broadband Ocean Bottom Seismometers with Hydrophones (OBS/H). The OBSSP was equipped with a SM-6 geophone (natural frequency of 4.5 Hz), while the OBS/H with a Guralp CMG40T-OBS (flat response between 60 s and 100 Hz) and a HTI-Hydrophone (flat response between 10 Hz and 8 kHz), both connected to a low power high performance digitizer developed by OBSLab–INGV's staff. The signals were sampled at a frequency of 200 samples/s with a 16-bit resolution. The Seascan SISMTB version 4.0 clock was used for the precise internal synchronization. All the instruments well recorded seismic data (high signal-to-noise shot signals and several local earthquakes). The OBSsSP have been recovered at the end of the Tomo-Etna experiment while the OBSs/H will be recovered in November 2014 in way to record for a longer time the regional natural seismicity.

New high resolution shipborne magnetic data were acquired offshore Etna volcano covering either major structural features of Timpe area and Riposto ridge. The magnetic data were collected using a Geometrics G880 caesium-pumped marine magnetometers towed 180 m astern of R/V Galatea. 1-Hz raw readings were real-time geographically referenced using GPS positions furnished by the main navigation system (differential correction by using a Fugro Marinestar VBS). Magnetic survey was planned using a line-path oriented along NE-SW direction in order to intersect the major structural–volcanic features offshore Etna. A total of 1340 linear kilometers of magnetic track lines were acquired using a set of 64 NE-SW parallel lines (with a spacing of 250-300 m) and 8 orthogonal tie lines. Raw magnetic data were processed removing spikes and intervening outliers records, further statistical levelling provided a smooth distribution of magnetic pattern of survey area. The Timpe area shows an high amplitude (>700 nT) magnetic anomaly associated with the main structural elements (NW-SE faults system) suggesting a clear interplay between the tectonic setting and the volcanic manifestations. Interesting magnetic features are observed over the Riposto ridge where small high-frequency positive anomalies (200 nT) are correlated to two small E-W structural highs.

The Riposto ridge was also directly investigated by several ROV dives using a Sirio ROV by Ageotec (operating depth 300 m). ROV dives were focused on the Riposto Shoal (a NE-SW trending complex structure deeply affected by scarps with the top located at water depth of 66 m) and offshore Fondachello where several morphological highs were previously observed on the basis of HR bathymetry [Chiocci et al., 2011]. On the Riposto Shoal ROV dives reveal the presence of volcanic blocks and lava flows only partially incrusted. Same samples recovered by ROV confirmed the presence of volcanic rocks on the shoal. In the same area mounds-like structures, teens of meter large with an height up to 15 m and with piles of volcanic pebbles at their basis, were observed. Off Fondachello in water depths between 70 to 150 m, several morphological highs have been identified. Some of them show an hard massive lithology highlighted by conchoidal fractures and columnar joints, typical of volcanic outcrops. Other are up to 4 m high mounds-like structures showing a sub-rounded shape; at their basis a well sorted deposit of decimetre-size lava pebbles (sampled by ROV) occur. No gas emissions were founded on the Riposto ridge.

The framework presented is preliminary; the complexity of the geologic setting of the area needs further geophysical investigations with the same multidisciplinary approach.

TOMO-ETNA: an Active Seismic Experiment at Etna Volcano

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In the frame of MEDSUV and Eurofleets2 European projects, an active seismic experiment has been performed on Eastern Sicily and Aeolian islands. The experiment lasted from June 20 through July 20, 2014 involving more than 70 scientific personnel from the Spain, Italy, Germany, Ireland, Russia, USA and Mexico institutions. The aim was to perform a high resolution velocity and attenuation tomography to investigate on the regional tectonic structures extending from the Southern Tyrrhenian sea towards the Ionian and their interaction with the Etna plumbing system. This study could permit to make progress in the understanding of the internal structure of Etna volcano. For the purpose, onshore and offshore seismic stations were deployed in order to record induced (air gun shots) and natural (local seismicity) seismic signals. A dense local seismic network consisting of 98 on-land temporary stations (80 short period and 18 BB stations provided by the GFZ -Potsdam), and about 70 on-land permanent stations of INGV, leading to a total of 168 seismic stations have been installed. A total of 13,292 air gun shots were produced by the

Spanish Oceanographic vessel "Sarmiento de Gamboa CSIC-UTM", and recorded by the on-land seismic network and by 27 OBSs deployed in the Ionian and Tyrrhenian sea (Figure 1).

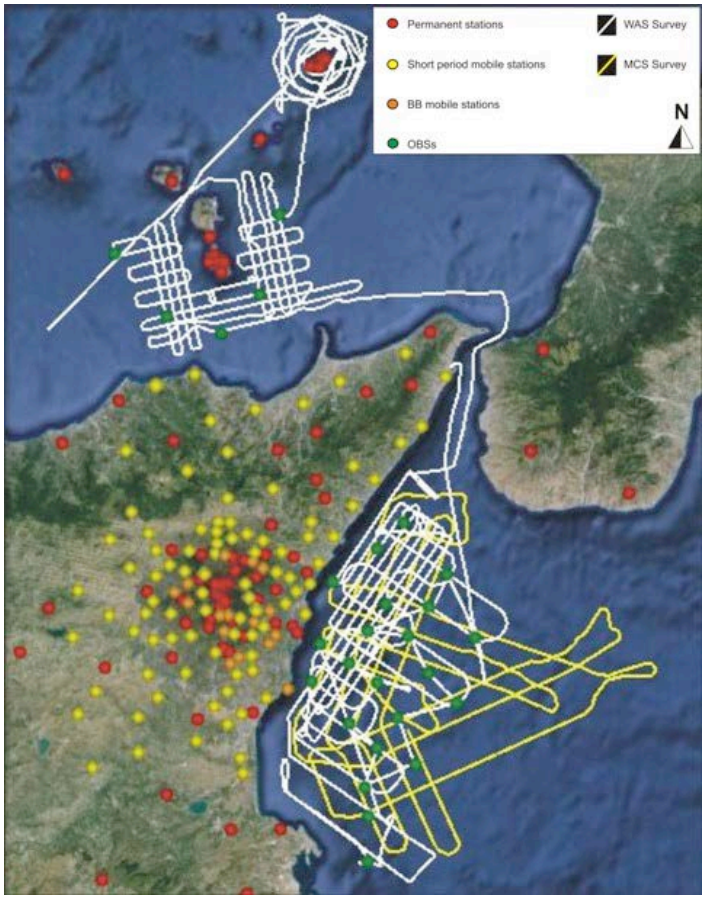

Figure 1. On-land and off-shore seismic network deployed during the experiment. Reflection and refraction routes are also drawn.

About 1880 km, corresponding to almost 9400 shots (every 90 s) of refraction data (WAS wide angle seismic) were acquired both in the Ionian and in the Tyrrhenian seas shooting at the maximum available airgun volume (5200 cubic inches). Furthermore, reflection lines (620 km of MCS multichannel seismic) were acquired in the Ionian Sea using a 3 km long streamer with 240 channels, coupled with a 4340 c.i. air-gun source. Shots were performed every some 20 seconds. The experiments will provide a unique data set in terms of quantity and quality of the recorded signals. TOMO-ETNA was also supported by the active participation of the Marina Militare Italiana and by the Dipartimento di Protezione Civile della Regione Siciliana. It is noteworthy that, during the experiment Etna volcano was active with strombolian activity and lava flows.

Ash Leachates from Mt. Etna (Italy) and Popocatepetl (Mexico) Volcanoes and their Impact on Ernivronment

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Generation and dispersal of volcanic ash during explosive eruptions can impact the environment at a serious level. Ashfall on natural waters and water supplies induces pH variations and alters the natural concentrations of chemical elements. Several eruptions have resulted in contamination of pasture, sometimes with serious impacts on livestock.

The study was carried out on different samples ash leachates of different samples of volcanic ash, in order to evaluate the different release of chemical compounds in the environment.

Samples from the eruptions of Mt. Etna (Sicily) of April 24, 2012 and August 12, 2011 and Popocatépetl 2012 (Mexico) represent an opportunity to study fresh ash leachates.

The samples have been characterized by XRF and XRD on bulk rock and SEM-EDS on glass and mineral phases.

Leaching experiments were carried out using mQ-water and water samples from Lake Ohrid (Macedonia-Albania). Both waters were previously characterized using surface electrode, gas electrode, ion-chromatography and ICP-MS. During the experiments the pH variation, the concentration of chemical compounds and saturation index were determined. It was observed alkalinisation in Etna leachates samples and acidification in Popo leachates samples with different release of anions and cations; in particular Etna leachates are rich in F^- and Popo leachates are rich in SO_4^{-2}. Many of the elements that have been measured are included in the drinking water guidelines due to their potential toxicity. In many of the analyzed ash leachates F^-, Mn^{+2}, SO_4^{-2} and Fe^{+2} concentrations exceed the maximum values defined by Italian law (for examples the maximum value of F is 1.5 g/l, while F concentration in Etna ash leachates reaches the value of 20 mg/l). The ash leachates were also used for conducting toxicity laboratory experiments on living biotic (i.e. tadpole). The results highlight the potential impact of volcanic ash deposition on environment, animals and human health.

High Resolution Aeromagnetic Anomaly Map of Mount Etna Volcano, Southern Italy

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A high resolution aeromagnetic survey was carried out by Istituto Nazionale di Geofisica e Vulcanologia (INGV) in May 2012, covering completely all the Etna volcanic province around an area of about 60x60 km, including both onshore and offshore sectors [D'Ajello et al., 2014]. In order to take into account high topographic variations of Mount Etna, two surveys at different constant elevations were acquired to optimize the magnetic signal sampling: one survey was flown at an altitude of 2200 m whereas a second survey, covering the central portion of Etna volcano, was performed at 3500m asl. Both survey areas were acquired through aeromagnetic profiles +80°N oriented, orthogonally to the main regional structural directions [Azzaro et al., 2012] and line spaced 1 km apart.

In volcanoes characterized by intense effusive activity, such as Etna, recent lava flows tends to cover almost the previous volcanic phases, making difficult an accurate reconstruction of its evolution. This new survey defines the Etna magnetic signature at the date of the campaign, which turns to be useful for future aeromagnetic acquisitions.

The most important evidence revealed by the present magnetic observation is that there is no correlation between Etna magnetic signature and its topographic structure. In fact the magnetic anomaly lies mainly in correspondence of the southeast instable flank of Etna, where the main identified tectonic lineaments occur.

From the residual magnetic anomaly analysis we inferred two main trending lineaments(-35°N and 0°), related to regional tectonic stress field and we interpret the main magnetic anomaly as the effect of thickness variation of magnetized volcanic products due to the complex pre-volcanic basement morphology of Etna [Branca e Ferrara, 2013; Nicolosi et al., 2014]; this implies that the magnetic signal is strongly controlled by variations in volcanic unit thickness, that filled the pre-volcanic basement huge depression.

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The Mt Etna Plumbing System from Velocity and Attenuation Tomography: Results from 1994 until Present Datasets

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Several papers have contributed to understand the Mt. Etna plumbing system. The intense seismic and volcanic activity allows collecting superb seismological data that reveal both the geometry of magmatic and intrusive bodies at depth and transient changes of velocity and attenuation during large eruptions. In this study, we use the most complete set of high quality P and S-wave arrivals, covering the 1994–present period and recorded by permanent and temporary networks.

Vp, Vp/Vs and P-wave attenuation tomographic models yield robust imaging of the structure down to 15 km depth. We find annular low Vp, low Qp anomalies around a high Vp, high Qp plug at mid-crustal depth. We hypothesize that the magma upraises around the central plug up to 3 km depth (b.s.l.) and is channeled toward the central eruptive system by a set of circular shallow faults of which the Copernicana represents the northern limit. Diffuse seismicity occurring within a low Vp, high Vp/Vs anomaly at 5 to 6 km depth to the east of the volcano probably represents a creeping volume, forced by magma pushing, and related to the eastward collapse of the edifice.

A Song of Mud and Fire: the Impact of Volcanic and Related Phenomena on Human Settlements at Ischia, from Neolithic to Roman Times

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The volcanic area around the Bay of Naples, in Italy, is one of the most impressive examples of how volcanoes have greatly influenced the growth and decline of human settlements since prehistoric times. This long history of human experience of volcanoes is recorded in detail in the stratigraphy of the Campania Region, where archaeological and volcanological researches have contributed to the understanding of settlement and human activity in this area from the Late Neolithic until historical times. The island of Ischia in particular has experienced a complex history of human colonization alternating with volcanic eruptions that destroyed settlements and drove away the population.

When the first humans settled on the island, in around the middle of the 4th millennium BC, the Ischia volcano was dormant for a quite long time. After the effusive eruptions that marked the beginning of the last period of volcanic activity at about 10 ka, a long interval of an almost continuous quiescence followed, likely interrupted at around 6 ka by the eruptions that formed the a lava field, in the north-western corner of the island, and by a phreatomagmatic eruption in the south-east. It is also possible that the pumice-cone-forming eruptions that represents the first steps of evolution of the Mt. Rotaro composite volcano, occurred in a time-span included between 8.5 and 5.5 ky. The northern part of the island was still submerged at that time, as testified by the deposition of marine sediments, dated at 8.5 ka, and presently exposed in various outcrops along the sea-cliff and at the base of the Mt. Rotaro volcanic sequence.

A very fertile soil, developed above an old sequence of ash deposits, extended over the whole south-eastern sector of the island, which at the time of the Neolithic settlement, very likely appeared as a lush, grassy valley, bordered by wooded hills.

This environment and the human settlement were devastated by two powerful phreatomagmatic eruptions, which followed to each other in a short time span.

As demonstrated by recent geological studies renewal of volcanism was always foreshadowed by the emplacement of deposits generated by surface gravitational movements, induced by reactivation of vertical movements, which were in turn responsible for the generation of faults and fractures that fed volcanism. These deposits were generated in four main phases, dated between 5.5 and 2.9 ky, around 2.9 ka, between 2.6 and 2.3 ky, and between 2.3 and 1.9 ky, respectively.

The first phase of landslide generation is characterized by the deposition of a debris-flow sequence, after the emplacement of the Piano Liguori Tephra and the Costa Sparaina Lavas.

During the second phase, archaeological data testify that surface gravitational movements shortly predated the emplacement of the Chiarito Tephra (8th century BC). Part of the first Greek settlement on Ischia was destroyed by this eruption. Remobilization of the Cannavale Tephra deposits (2.9 ka) and the absence of erosional unconformities and paleosols between this tephra and the overlying landslide deposits, likely suggest that slope instability also accompanied and shortly followed volcanism during this phase.

The third phase (2.6-2.3 ky) includes deposits emplaced during at least 300 years of continuous volcanic and slope instability activity. Archaeological data suggest the emplacement of debris avalanche deposits soon after (about one century) the Chiarito Tephra eruption, determining the VI century B.C. resettled colonists to definitively abandon the site. Lack of erosion or humification at the bottom and top of the Vateliero Tephra (6-4th century BC), suggests that this eruption likely was briefly preceded and followed by the emplacement of debris-flow deposits. During the 5th century BC the Ischia Porto eruption had a devastating local impact, destroying the Syracusan military settlement and modifying the aspect of the surrounding landscape, with the creation of a new lake. The S. Pietro Hill was occupied again in Roman times, when two other volcanic episodes impacted this sector of the island.

In the 4th Century BC slope collapses and lahars widely affected the western sector of the island, almost contemporaneously to the Cava Bianca eruption, which occurred on the opposite side of Mt. Epomeo.

The landslide deposits of the fourth phase contain archaeological findings dated at the 1st – 2nd century A.D. Portions of the Ctretaio Tephra locally imbedded in debris-flow and debris-avalanche deposits suggests that they were emplaced during or soon after the Cretaio eruption, which determined the sinking of

a Roman foundry along the south-eastern shore of the island. During the 2nd and 3rd centuries, some lahars flooded Roman villages in the western sector of the island.

The last eruption on the island occurred in 1302 A.D., also being preceded by a possible fifth phase of major mass movement generation.

Geochemical Investigations for the Assessment of Geothermal Resources in Sicily (southern Italy)

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We present an ongoing research project on geochemical study applied to geothermal investigation in Sicily (southern Italy). The Sicily region counts many geothermal manifestations (thermal waters, gas vents and mud volcanoes) and hosts several typologies of geothermal systems, ranging from the high enthalpy geothermal systems in volcanic islands to medium and low enthalpy systems in the mainland, apparently not related to specific igneous intrusions. The variability of geothermal aspects is related to the complex geological structure of the region. Sicily is a sector of the south-verging Apennine-Maghrebian orogenic belt, stacked since Late Oligocene and located along the African-European plate boundary in the Mediterranean area. The belt results from the deformation of nappes belonging to different paleo-geographic domain. In central and western Sicily, along the outcrops of the regional geothermal reservoir hosted mainly in Mesozoic to Cenozoic carbonate rocks, several thermal springs (T. Segestane and T. Gorga, Montevago and T. Selinuntine, Termini Imerese, Sclafani and A. Fitusa) occur. This area is characterized by active tectonic processes that affect the hydrothermal circulation as revealed by the historical closure and opening of springs after earthquakes (A. Calda di S. Lorenzo). Mud volcanoes and dry methane vents are typical manifestations of the south-western Sicily, in the thick sequences of evaporitic, clastic and pelagic deposits related of Miocene to Pleistocene that filled the Caltanissetta basin. The southestearn part of the region consists of a thick sequences of carbonate rocks (Hyblean foreland) and intercalated volcanics erupted during several episodes since Cretaceous. The main manifestations of this area occur in the Naftia, Bongiovanni and Pisana wells. More manifestations are present also in the northeastern region along both the Tyrrhenian coast (Capo Calavà and T. Vigliatore) and the Ionian coast (Granata Cassibile and T. Marino), where crystalline rocks (Peloritani units) outcrops diffusely. Geochemical exploration provides useful information regarding the physical and chemical characteristics of hydrothermal circulation and heat source at depth. Thanks to two recent geothermal projects carried out in southern Italy, a comprehensive data review has been already carried out. In the frame of the Geothermal Atlas Project, aimed at characterizing, classifying and mapping the conventional and non-conventional geothermal resources for electricity production in the regions of southern Italy, it was possible to collect and review the volcanological and geothermal information available in literature, and to organize a geochemical database. The VIGOR Project and its evaluation of geothermal potential produced, among other results, a review of the main structural settings and the reconstruction of the top of the regional geothermal reservoir [Montanari et al., 2014]. These activities evidenced the complex relation between geothermal systems and tectonic setting of Sicily, and pinpointed what information are still lacking for an overall understanding of the origin and circulation of hydrothermal fluids and the differentiated thermal structure of Sicilian crust in the various sectors. This base of information represent the starting point of the actual research, which aims to: i) increase knowledge on the origin of this fluids (thermal waters, gas vents and mud volcanoes) and on the heat sources of the geothermal systems; ii) understand the relationship between fluids and the geological-tectonic setting of the study area; iii) provide interpretative models useful for further exploitation of deep geothermal resources with traditional and modern technologies. To this aim, we will study a sector of the "collisional" complex of Sicily performing the geochemical measurements along a northwest-southeast transect from T. Segestane towards Naftia (Fig.1).

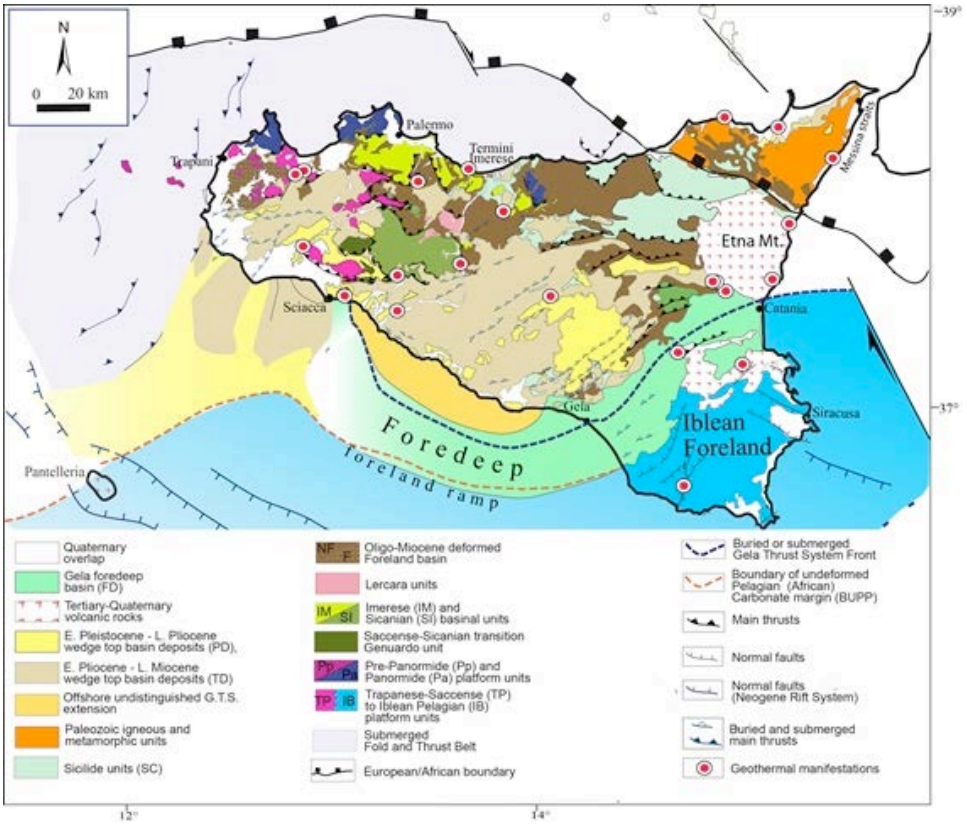

Figure 1. Geological-structural map of Sicily (modified from [Montanari et al. 2014]). The main geothermal manifestations are also shown.

We plan to measure new geochemical data and create a dataset that includes not only the analysis of the major compounds but also the isotopic signatures of CO_2, CH_4, N_2, He and VOCs released into air. The data will be then integrated with geological and geophysical data collected and provided by Geothermal Atlas and VIGOR Projects.

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Oldest Volcanic Units at Mt. Amiata (Tuscany, Central Italy) Discovered inside "Davide Lazzaretti" Well

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Mt. Amiata is a 1738 m-high volcanic complex dominated by trachydacitic lava flows and domes with a few late-erupted shoshonites and latites whose emplacement occurred between 300 ka and 200 ka [Ferrari et al., 1996; Cadoux and Pinti, 2009].

An exploration well named "Davide Lazzaretti" (hereinafter referred as DLW) was drilled, during the year 2010, by the Tuscan regional authority, in the southern part of Mt. Amiata volcano (Tuscany, Central Italy) in order to gather data for hydrogeological purposes. The results of the petrographic study of this drilling are here presented for the first time.

DLW was drilled near the village of Santa Fiora (GR), close to the Poggio Trauzzolo lava dome at an altitude of 1086 m above sea level (a.s.l.), it reached a depth of 545 m below ground level (b.g.l.; i.e. 541 m a.s.l.) and was almost entirely continuous core recovered except the superficial 60 m. DLW crossed the volcanic complex and, at 530 m b.g.l., reached the sedimentary substratum, consisting of deformed greenish shaly sediments with interbedded layers of very fine-grained siliceous limestones (i.e. Palombini shales outcropping in the southern side of the volcano).

We studied the sequence drilled by the DLW in order to investigate the volcanic stratigraphy, carrying out facies analyses, textural and petrographic study. Therefore, we identify the number and type of fractures and the eventual presence of hydrothermal circulation [La Felice et al., 2014]. The lithofacies distinction was based on a combination of primary lithological characteristics (vesicularity, phenocrysts, groundmass texture). In the drilled volcanic sequence, mainly two lithofacies associations are identified and interpreted respectively as lava flows and lava domes. The study of DLW allowed the gathering of a data-set useful to complete the stratigraphy of the Mt. Amiata volcanic sequence, in fact oldest volcanic units has been found inside the drilled sequence, under the known outcropping volcanics ($^{39}Ar/^{40}Ar$ dating is in progress).

According to Ferrari et al. [1996] the volcanic activity has developed in three main phases over a period of about 100,000 years, along a large fault-oriented ENE-WSW: i) unit BTC (Basal Trachydacite Complex); ii) unit DLC (Domes and Lava flows Complex); iii) units OLL (Olivin-Latite Lava flows). The BTC, the most voluminous unit cropping out with an average thickness of 150-200 meters, up to the present has been considered the older volcanic unit of the known sequence.

In the DLW, rocks correlated to the BTC unit were observed from top of the core until 317 m b.g.l. (about 250 m thick). It is a crystal-rich trachydacite with high porphyritic texture, medium to coarse grained with a peculiar flow banding. Broken crystals are abundant and xenoliths and magmatic enclaves are present. In the basal portion sub-vertical jointing and coalescence of adjacent vesicles are frequent. This extensive unit comprises, in our view, different, individual, superposed silicic lobes, in which we distinguish structural and morphological features typical of lava flows, such as basal and top autoclastic breccias, front structures and lateral termination.

From 317 m b.g.l., i.e. below rocks correlated to BTC, a new volcanic unit was found almost continuously until 530 m b.g.l., where it rest directly on top of the sedimentary substratum without any paleosol interposition. This oldest unit is composed of light-grey porphyritic trachydacite with distinctive presence of mega K-feldspars (up to 5 cm), set in a high vesicular and microcrystalline groundmass, which we interpret as lava dome lithofacies. This attribution is supported by the close similarity with lava lithofacies of the younger domes of the DLC unit. The abundance of xenoliths and large hypocrystalline greenish-grey magmatic enclaves (up to 20 cm) found in this core interval is also typical of dome lavas lithofacies at Mt. Amiata.

As a whole, the core succession is indicative of an aggradation of effusive products > 500 m thick and there is not evidence of pyroclastic deposits and/or mega-breccia facies.

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New Geological Mapping of Stromboli Volcano, scale 1:10 000, Providing insights on the Eruptive Behavior and Hazard Assessment

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A new geological map of Stromboli at 1:10 000 scale is performed by means of original geological and structural fieldwork and remote sensing analysis, combined with radiometric and palaeomagnetic ages from the literature and tephrochronological assignments, and a large set of petrochemical data. Fieldwork and mapping conform to a modern stratigraphic approach based on lithostratigraphic units (rock types and basic units for mapping), lithosomes (landforms and eruptive centres) and unconformity-bounded units (stratigraphic correlations). The stratigraphy of Stromboli is primarily organized in five synthems (Serro Barabba, V.ne di Rina, Frontone, Liscione, Sciara del Fuoco), eleven subsynthems and the informal Paleo-Stromboli unit by means of erosional unconformities of different rank corresponding to periods of quiescence mostly associated to five concentric calderas (cc1-5) and seven NW- and SE-dipping lateral collapses (sc1-7) (Fig. 1).

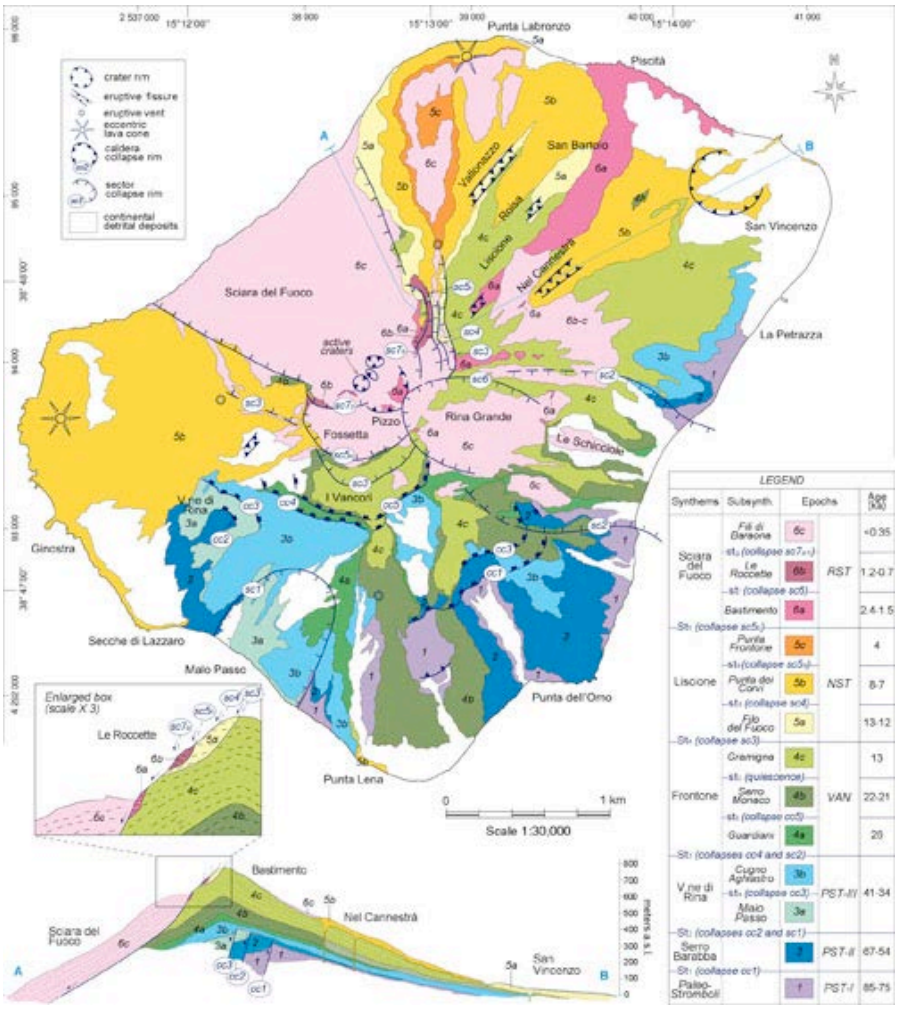

Figure 1. Simplified geological map of Stromboli in terms of Unconformity-Bounded Units, Eruptive Epochs (1-6; PST=Paleostromboli; VAN=Vancori; NST=Neostromboli; RST=Recent Stromboli) and collapse unconformities (cc=caldera; sc=sector collapse).

Accordingly, the eruptive, structural and magmatic history of Stromboli (except for the ~204 ka Strombolicchio neck) is described by six major growth stages (Eruptive Epochs 1-6) mostly corresponding to Paleostromboli I (85-75 ka), II (67-54 ka), III (41-34 ka), Vancori (26-13 ka), Neostromboli (13-4 ka) and Recent Stromboli (<2.4 ka), subdivided into sequences of eruptions. They are generally characterized by distinctive compositions of the erupted products, ranging from the calc-alkaline to potassic, through high-K calc-alkaline and shoshonitic series.

A particular focus in the map is placed on the Holocene to present-day volcanic units and structural features (younger than 13 ka), aimed at reconstructing the eruptive and collapse behavior and cyclicity with important insights on hazard assessment. Through the Holocene the activity was mostly supplied by summit vents located in the upper portion of the ongoing multi-stage Sciara del Fuoco collapse (Fig. 1), through recurrent phases of lateral failure and volcanism rejuvenation. Several flank eruptions along NE-trending fissures and vents are recognized in distinct time-stratigraphic intervals between 12.5 and 4 ka along the W and NE volcano slopes. Three distinct summit hydromagmatic eruptions are distinguished during the Holocene at c. 12.5, 7 and 4 ka, more probably linked to successive lateral collapses. These eruptions produced highly mobile pyroclastic density currents able to reach the lower volcano slopes and settled areas with potentially destructive effects, as a previously underscored source of volcanic hazard on Stromboli. Further insights on hazard assessment are provided by a detailed mapping of the most recent scoria products and lava flows erupted during the Present-day activity starting from the 8th century. Thick accumulations of loose black scoriaceous lapilli and bombs related to the normal strombolian fallout activity are emplaced in the area around the summit craters and along Sciara del Fuoco, interlayered with successive pahoehoe to aa lava flow fields occasionally produced during the last century by the summit vents or fissures opened inside the collapse. This means that the Sciara del Fuoco collapse acts as a topographic barrier for the distribution of volcanogenic flows during the most recent activity of Stromboli, as typically illustrated by the 2002 and 2007 eruptions (and the ongoing 2014 one). Our map and stratigraphy illustrate the occurrence of a number of lava overflows of the collapse through the Holocene, with the latest recorded in the High Middle Ages. The blocks and scoriaceous bombs, as well as the typical pyroclastic deposits bearing a bimodal juvenile component (HP scoriae and LP golden pumices) erupted during the most powerful higher-energy explosions called paroxysms (16th century, AD 1631-1730, AD 1930) are recognized and mapped by means of proper symbols along most of the volcano slopes up to lower elevations (occasionally affecting the settled areas of Stromboli and Ginostra). A main outcome for hazard from the geological map is the recognition of very recent episodes of medium to large-scale lateral failure along the flanks of Stromboli. A SE-dipping flank collapse is assumed to have truncated the summit Pizzo cone at 1.8–1.2 ka, as an evidence of gravitational instabilities also along the SE flank of Stromboli (which are usually undervalued). A major collapse along the NW flank of Stromboli is instead documented in the Late Middle Ages (0.7-0.35 ka), interrupting the Present-day activity and leading to the development of Sciara del Fuoco in its present morphology. This indicates that collapse events with potentially catastrophic effects (landslide movements and tsunami) during the Holocene to present-day history have been more frequent than previously thought, with a recurrence time of some hundreds to a few thousands of years.

Conservation of Volcanic Landscapes: a Multidisciplinary Approach for the Delimitation of the Main Volcanic Edifices of Sardinia (Italy)

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Unequivocal delimitation of landforms is a general objective that needs to be pursued for different purposes, both scientific, as the general morphometric analysis of a given set of landforms, and applicative, as the conservation of the natural heritage. The continuously increasing capability of manipulating digital elevation model (DEM) data gives now the possibility of adopting tools for the automatic recognition and delimitation of specific landforms, and these tools are important for obtaining objective results that are not heavily dependent on the subjective choices of an operator. This assumes particular importance when the delimitation of a given landform is required for conservation purposes, where the delimited area is to be subject to specific regulations or laws.

In the last few decades, public administrations have spent an increasing effort in landscape conservation trough constraining/instituting areas of naturalistic and landscape interest. In the framework of the application of the Article 142 of the Italian "Cultural Heritage and Landscape Code", Legislative Decree 42/2004, that states that volcanoes are areas protected by law, a detailed study aimed at identifying and delimiting Cenozoic volcanic edifices present in Sardinia was performed.

Due to the wide spectrum of type, age, erosion and forming conditions, resulting in an extremely variable shape and dimension of the volcanic edifices and in complexity of their surroundings, volcanic landforms from Sardinia offer a suitable case study to test the efficiency of existing algorithms and to develop new algorithms aimed at delimiting volcanic edifices. External boundary delimitation of the edifices has been based on an integrated methodology using automatic elaboration of digital elevation models together with geomorphological and geological observations. Three different elaborations of surface slope and profile curvature are proposed and discussed; among them, two algorithms based on simple mathematical functions combining slope and profile curvature well fit the requirements of this study. One of theses algorithms is a modification of a function already discussed by Grosse et al. [2012], which better perform for recognizing and tracing the boundary between the volcanic scoria cone and its basement. Although the geological constraints still drive the final decision, the proposed method improves the existing tools for a semi-automatic tracing of the boundaries.

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Imaging the Earliest Shallow Feeder System of Etna Volcano from Aeromagnetic Data

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Mount Etna is a basaltic composite stratovolcano formed through a complex geological evolution during the past 500 ka in eastern Sicily [Branca et al., 2011]. Following an earliest phase of discontinuous fissure type volcanism the eruptive activity was concentrated along the Ionian coast since at least 220 ka. In this phase, named Timpe, an almost continuous effusive activity formed a primitive volcanic structure on Etna region inferred as a lava shield. One of the main step in the geological history of Etna volcano occurred around 129 ka ago [De Beni et alii, 2011] as consequence of the westward shifting of the main shallow feeder system from the coast to the central portion of the present Etna edifice in the Val Calanna area. In particular, in this area occurred the stabilization of the magma source and the beginning of the central-type Etnean volcanism. During this phase, named Valle del Bove, the growth of several small polygenic volcanic centers occurred due to both explosive and effusive activity from central vents. In particular, the early edifices recognized are represented by Tarderia, Rocche and Trifoglietto volcanoes whose activity ended between 106 ka and 99 ka ago [De Beni et al., 2011].

Highly weathered and tectonized volcanics crop out in Val Calanna forming the relief of Mt. Calanna and the base of Mt. Fior di Cosimo. They are formed by cataclastic lavas with a highly hydrothermally altered yellow clay matrix associated with a complex of dikes. The lavas and most of the dikes are also affected by a strong hydrothermal alteration and tectonic fractures. According to Ferlito and Nicotra [2010] more than 200 dykes crop out at Mt. Calanna evidencing the presence of a dyke swarm in this area interpreted as the remains of the uppermost portion of the shallow feeder system that fed the earlier central-type activity of etnean volcanism. These highly weathered and tectonized volcanics are also exposed in a drainage gallery about 1.5 km southward of Mt. Fior di Cosimo, indicating a southward extension for the Calanna volcanics [Branca et al., 2011].

A new high resolution aeromagnetic survey was carried out during 2012 by Istituto Nazionale di Geofisica e Vulcanologia and a resulting anomaly map of the Etna volcanic complex was published [D'Ajello Caracciolo et al., 2014]. This anomaly dataset was used to model the pre-volcanic surface morphology and to highlight some sub-volcanic structures [Nicolosi et al., 2014]; one of the most evident is marked by a magnetic low, round shaped anomaly, located in the Val Calanna area. We present new analysis of this magnetic anomaly low to image the subsurface geometry using a potential field inversion approach; we highlight the real extension of the low magnetized area that is characterized by a sub-circular shape of about 3 km radius centered in Monte Fior di Cosimo area. We interpret this low magnetized area as an altered feeder system of the earliest Etna central volcanic activity. Therefore, the highly weathered and tectonized dyke swarm recognized at Mt. Calanna by Ferlito and Nicotra [2010] represents the only surface evidence of a large sub-circular shallow plumbing system that fed the final stage of the Timpe phase volcanism and the beginning of the construction of first central edifices in Etna region during the Valle del Bove phase.

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Pre-volcanic Basement Geometry and Flank Instability Correlation from Aeromagnetic Anomaly Data Analysis of Etna Volcano, Italy

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The knowledge of basement geometry and lithology underlying active volcanoes plays a key role in understanding and modelling their deformation field and associate hazard. Since volcanoes basement geometry is generally masked and covered by volcanic successions, its morphology is frequently modeled by simple flat surface geometries or constant step planes. These simplified models could underestimates the importance of volcanoes- basement interaction.

Using a new high resolution aeromagnetic anomaly dataset [D'Ajello Caracciolo et al., 2014], acquired during 2012 by INGV, we model the geometry of the magnetic bottom surface of Mount Etna volcano, that mainly corresponds to the pre volcanic basement morphology; this surface can be well resolved by magnetic inversion modelling approach due to the high magnetic contrasts between volcanic products and non-magnetic clay rich basement lithologies. Taking into account the relative compositional homogeneity of Etna products, we consider the internal magnetization variations mainly due to volcanic pile. We assume that a bulk magnetization of the volcano describes the observed magnetic anomalies and the main magnetization contrasts are due to thickness variations of volcanic pile formations. A bulk magnetization value of 8 A/m minimizes the RMS error on the data.

The resulting Etna sedimentary basement model shows an asymmetric topography with a wide depression located below the south eastern flank of the edifice; this hidden basement morphology has recently been highlighted using different geophysical methodology [Branca and Ferrara, 2013] and our new model independently confirm and detail the deepest part of this depression. The geometry of the Etna non-magnetic basement is fully consistent with that of a huge, east facing landslide depression preexisting the construction of the volcano. This morphology provide evidence for a large stratovolcano growing on a pre existing basement landslide and show that the eastern Etna flank moved coherently with the underlying landslide. The filling of the landslide depression by lava flows thorough time allows the formation of a stiffness barrier, which is responsible for the long time migration of the magma pathways from the coast to the present-day Etna summit [Nicolosi et al., 2014].

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Investigation of the Near Surface Wave Propagation of Tectonic and Volcanic Earthquakes at Etna

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Over the last few years it is growing the need to monitor the volcanic activity with modern technology in order to mitigate volcanic hazard through the detection of any possible precursor phenomena. Therefore a continuous monitoring of seismic activity is a fundamental task to detect the most common signals possibly related to imminent volcanic activity, such as volcano-tectonic earthquakes, long-period events, and volcanic tremor. The use of high performance seismic stations, such as borehole instruments, may increase the Signal to Noise Ratio (SNR), improving the capability to detect very small signals. Over the past 40 years much attention has been given to the use of seismic arrays to measure the slowness vector of coherent signals. Compared to classical seismic networks, the main advantage of seismic arrays consists in their ability to detect weak or emergent signals, and to allow for an effective noise reduction through multichannel waveform stacking.

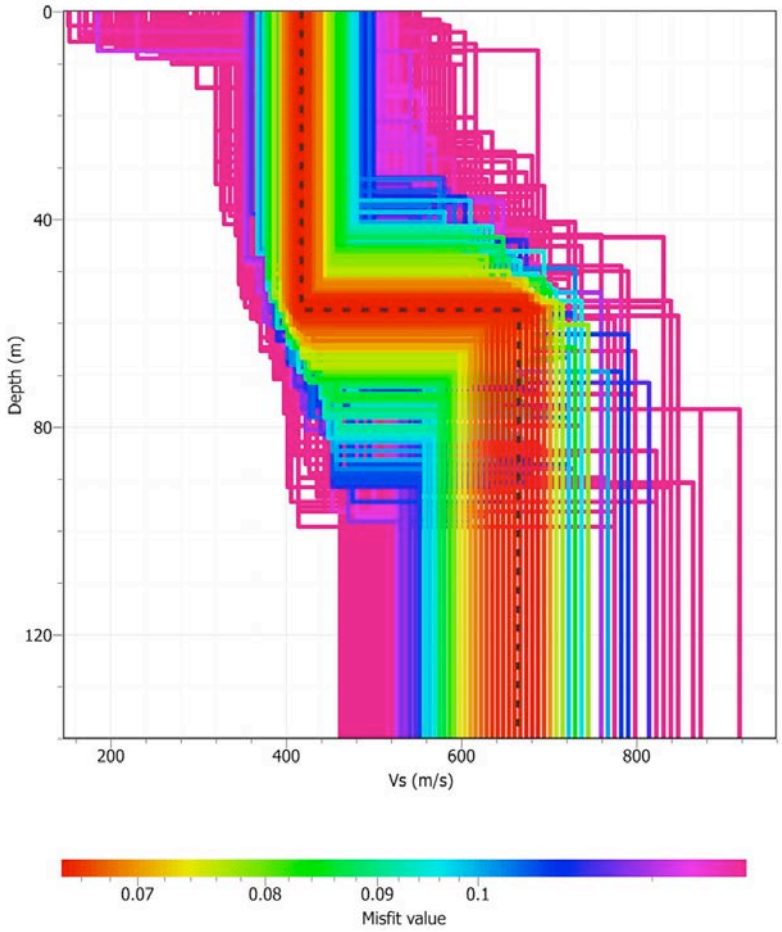

Figure 1. 1D Shear-Velocity Profiles obtained by the inversion of the associated fundamental Rayleigh-wave dispersion curves using the neighborhood algorithm. The velocity value is corresponding to a misfit value of about 0.06 (dotted line).

A reliable prediction of the ray-path propagated back from the recording site to the source is strongly limited by the poor knowledge of the local shallow velocity structure. Usually in volcanic environments the shallowest few hundreds meters of rock are characterized by strongly variable mechanical properties. Therefore the propagation of seismic signals through these shallow layers is strongly affected by lateral heterogeneity, attenuation, scattering, and interaction with the free surface.

Driven by these motivations, on May 2014 we deployed a seismic array in the area called "Pozzo Pitarrone", where two seismic stations of the local monitoring network are installed, one at surface and one borehole at a depth of about 130 meters. The Pitarrone borehole is located in the middle northeastern flank along one of the main intrusion zones of Etna volcano, the so called NE-rift. It consists of a mean network of sub-parallel eruptive fissures striking from 42°E to 47°E and extending from the surface (1700 m a.s.l) down to 2500 m depth. The NE-Rift is delimited eastward by a 200 m-high fault scarp in Piano Provenzana area. This fault together with the Pernicana and Fiumefreddo faults are commonly indicated as discrete segments of a near continuous left-lateral shear zone that dissects this sector of Etna. The temporary deployed array is composed of 8 broad band seismic stations installed at distances of a few hundred meters around the Pitarrone well. Therefore in that area we have a 3D sampling of the seismic wavefield. With the 3D array we record seismic signals coming from the summit craters, and also from the seismogenetic fault called Pernicana Fault, which is located nearby. The analysis of such data set will improve our knowledge about the (i) structure of the top layer and its relationship with geology, (ii) analysis of the signal to noise ratio (SNR) of volcanic signals as a function of frequency, (iii) study of seismic ray-path deformation caused by the interaction of the seismic waves with the free surface, (iv) evaluation of the attenuation of the seismic signals correlated with the volcanic activity. The results of these analyses will improve the general knowledge of wave propagation in the shallow layers and will give an new contribution to the seismic monitoring of Etna volcano.

The seismic array, that is part of the project MEDSUV funded by the Eurepean Community, was installed in collaboration with the colleagues of Osservatorio Vesuviano (INGV). The data acquisition is planned to last until the end of September 2014.

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SESSION 2

Eruptive Dynamics and Depositional Mechanisms

Understanding the Mechanisms Driving Large-Scale Basic Plinian Eruptions from Textural and Rheological Studies on the Pozzolane Nere Eruption (Colli Albani, Italy)

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The Pozzolane Nere formation (PNR) represents one of the largest explosive events in the history of the Colli Albani volcano (407 ka, Vulcano Laziale phase). The PNR is characterized by a basal scoria fallout deposit showing an east-trending axis of dispersion overlain by a widespread low aspect ratio ignimbrite, estimated at 30 km^3 as bulk volume. PNR magmas are very undersaturated, tephri-phonolitic in composition and represent the basic end-member of the spectrum of explosive caldera-forming eruptions. Despite extensive studies on the deposits of the volcano, the mechanisms governing the explosive activity of these magmas are still poorly known. In order to understand the role of the internal properties of magmas in influencing and guiding the dynamic of magma ascent and eruption we carried out a combined investigation of structural features of the deposits (grain-size, maximum clast size, composition), textural, physical and chemical characteristics of the juvenile material (Vesicle Size Distributions, Crystal Size Distribution, density, viscosity) and eruption parameters (ejected volume, column height and discharge rate).

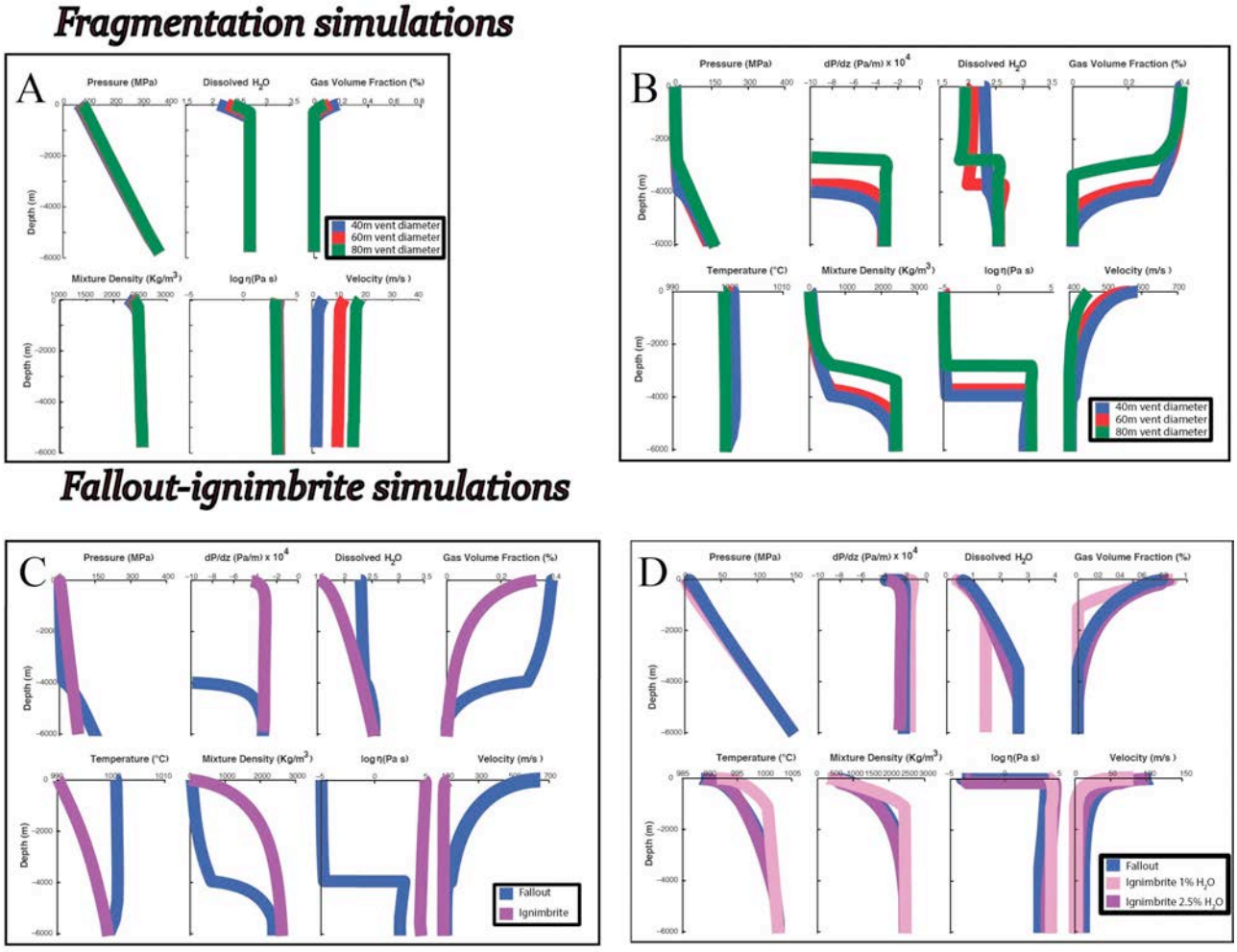

Figure 1. Fragmentation simulations using A - the Papale [1999] criterion and B - the Spieler et al. [2004] criterion. C - fallout-ignimbrite transition simulation, also considering D - a loss of water.

Textural and minero-chemical investigations of the samples have been combined with their rheological characterization. Low T viscosity measurements (690°C<T<800°C) were performed by micropenetration technique, while the high T viscosities of fully molten (1250°C<T<1569°C) and partially crystallized specimens (1100°C <T<1225°C) were measured at 1 bar in air with a concentric cylinder viscometer. Above the liquidus temperature, viscosity ranges from 10^1.04 to 10^3.64 Pa s (HT) and 10^12.15 to 10^9.23 Pa s (LT) in good agreement with the viscosity model by Giordano et al. [2008]. In the subliquidus region, isothermal crystallization experiments allowed to quantify the role of crystals on the rheology of PNR magmas. Ten isothermal crystallization experiments were performed in the temperature range T=1193-1240°C with a constant strain rate at 0.1 s-1. The final viscosities ranged between 10^2.82 and 10^3.14 Pa s. The increase of apparent viscosity together with the onset of strain rate- and strain-dependent behavior could play a critical role during PNR degassing history, influencing the elevated explosivity of these very undersatured magmas.

Vesicle Number Densities (VNDs) are higher than those observed in literature for basic explosive eruptions and are more comparable to VNDs pertaining to explosive eruptions of evolved composition. We implemented the original version of CONFORT, the Fortran version of CONFLOW [Mastin and Ghiorso, 2000], inserting the most recent viscosity formulations [Giordano et al, 2008; Costa et al, 2009; Vona et al, 2011; Di Genova et al, 2013]. As far as PNR eruption is concerned, we demonstrated through numerical simulations that, at very fast decompression rates, despite the physical and chemical conditions (e.g. mafic composition, low viscosities and porosities) the condition necessary for fragmentation can be achieved. We postulated that water-magma interaction triggered the eruption, generating the fast decompression rates that allowed it to initiate and to progress into a purely magmatic stage. Changes in vent/conduit geometry are hypothesized to be responsible for the transition fallout-ignimbrite. We suggest opening of fractures and caldera collapse as responsible for an increase in mass discharge rates and a decrease in ascent velocities, which produced a final column collapse leading to the generation of great intensity ignimbrite, such as that relating to the PNR eruption.

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Textural and Rheological Constraints on the Fallout-PDCs Transitions of the Agnano-Monte Spina Eruption (Campi Flegrei, Italy)

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The 4.1 ka B.P. Agnano-Monte Spina eruption is the highest magnitude event of the past 5 ka at Campi Flegrei caldera. The six members of this eruption are a sequence of pumice- and scoria- falls and flows confined inside the Agnano plain.

Since the eruption style is moderated by differences in the magma fluid dynamics and the degassing path during the course of the eruption, in this study we investigated the textural characteristics and the physical properties of three members (A, B and D) of the main fallout and of the subsequent PDCs phases.

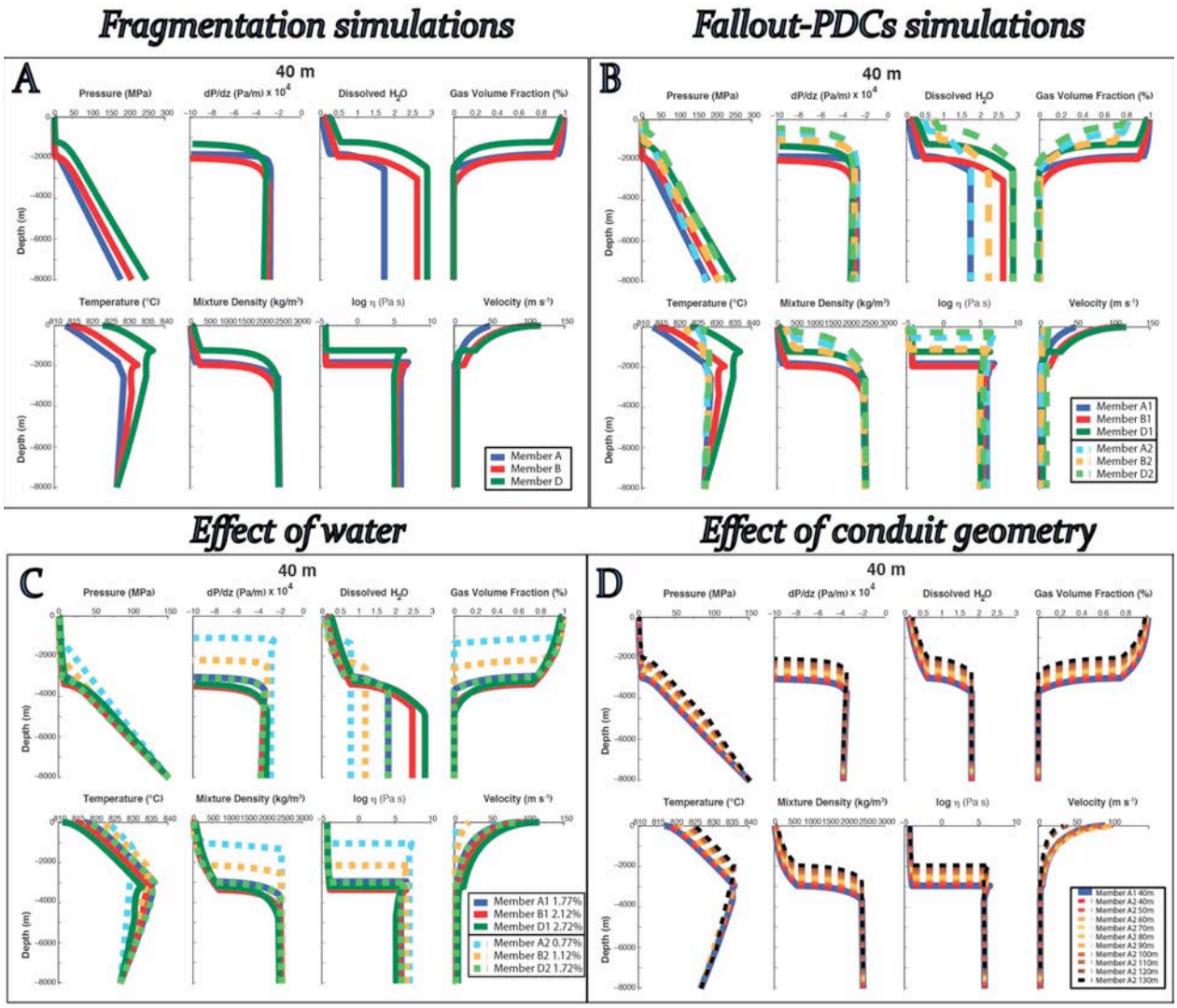

Figure 1. Assuming a vent diameter of 40 m A- the fragmentation processes, B- the fallout-PDCs transitions, C – the effect of the water for each fallout-PDC transition and D- the effect of the conduit geometry for the A member transition are presented.

We aim to relate the textural features of the deposit to variations of intrinsic parameters of the magma during ascent along the conduit and to investigate how the fluid dynamics of the magmatic mixtures may have influenced both the generation of the sustained activity and the collapse and generation of the PDCs phases. A combination of field, grain-size, density, Vesicle Size Distribution, Crystal Size Distribution, fine-ash morphologies, experimental viscosity investigations and numerical simulations was carried out. Each transition fallout/PDC (A1-A2, B1-B2, D1-D2) is accompanied by distinctive changes in textural properties of the magma, with drops in Vesicles Number Densities (VNDs) of about one order of magnitude (from 10^8 to 10^7 cm-3), indicating a remarkable decrease in ascent rates. These VNDs drops translate into a strong decrease in decompression rates in PDCs with respect to the decompression rates calculated for the respective fallouts. Vesicle volume distributions (VVD) are near-unimodal, as commonly observed for a distinct pulse of nucleation and growth generated by an explosive event. Compared to A1 and B1, D1 distribution shows a smaller variance and is depleted in large vesicles. These characteristics could reflect the higher explosivity of this phase possibly due to major magma ascent velocity. Partial collapses of the B1 column produced the basal pyroclastic surge deposits of B2. In B2 VNDs generally decrease by one order of magnitude, indicating a waning in the magma ascent rate and generating a first pyroclastic flow (B2-PF1), a surge deposit (B2-SD), a second pyroclastic flow (B2-PF2) and a final welded scoria deposit (B2-WSD). VVDs of B2-PF1 and B2-PF2 have polimodal distribution and present typical features of bubble coalescence, which developed both pre- and post- fragmentation. The B2-SD phase between the two flows, shows characteristics of a phreatomagmatic explosion (i.e. small, subspherical bubbles, index of interaction water-magma). The final B2-WSD displays the lowest overall porosity (40-50% compared to 75-85% of all the other deposits) and VND on the order of 10^5 cm^{-3}, similar to those of Strombolian eruptions. The distinctive decompression rates, initial water contents and minor changes in compositions are able to explain the different column height and volume erupted through the A1, B1, and D1 sequence of the eruption (5, 23 and 27 km respectively). We implemented the original version of CONFORT, the Fortran version of CONFLOW, [Mastin and Ghiorso, 2000] inserting more recent viscosity formulations. Numerical simulations, taking into account decompression rates derived from textural analyses and Toramaru [2006] formulations, are able to reproduce the strong decreases in exit velocities responsible for such transitions in eruptive styles. Both a change in intrinsic properties of the magma (water content decrease) and/or a change in conduit/vent geometry, could be responsible for the sudden drop in magma ascent rate and the generation of the pyroclastic density currents.

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Detection of Volcanic Plumes in Atmospheric Particulate of Distal Environments

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Atmospheric particulate (PM10 and PM2.5), aerosol size distribution and meteorological parameters are continuously measured at the CNR-ISAC Climatic Observatory of Lamezia Terme (Calabria) and at CNR-ISAC of Lecce (Apulia). The distances of the two observatories from the two continuously erupting volcanoes of Southern Italy are, respectively, 170 and 392 km from Etna and 85 and 304 km from Stromboli.

During the last 12 months some anomalous peaks in the concentration of atmospheric particulate were observed. The main positive anomaly recorded in the observatory of Lamezia Terme was on 19th November 2013, when an increase of factor 10 with respect to the averaged PM10 levels was observed. The ?intense? event in Lamezia Terme was also visible, with lower intensity and longer duration, in Lecce 5-6 hours later. In both cases the aerosol size distribution showed that the main increase was in the coarse fraction, generally ascribed to particles mechanically originated (sea spray, dust, volcanic ash).

The activity of Stromboli in that period was not more intense than usual. However, in the night between 16th and 17th November a paroxystic eruption occurred at Etna, from the New South East crater. The eruption was characterized by a violent strombolian activity, lava fountains, lava flows, and the formation of a pyroclastic column, several km high, moving towards NE.

Data obtained by MOLOCH (MOdello LOCale in H coordinates) meteorological forecasts showed that the global circulation on 19th-20th Nov in Southern Italy was directed from the Etna area towards North-East. A further constrain comes from the HYSPLIT forward trajectories from Etna on the same days, confirming a transport from Etna to central Calabria and Apulia. Finally, the SO_2 vertical column maps, made on the basis of NASA satellite observation, show a high SO_2 concentration above Etna on 17th Nov. On 19th Nov the SO_2 column is above the Calabria Tyrrhenian coastand continues to move toward Apulia. This supports the hypothesis that the volcanic plume of 17th Nov eruption reached Lamezia Terme and Lecce on 19th and it is responsible of the anomalous deposition of PM10 in both areas.

The PM10 filters of that week were observed by using the Scanning Electron Microscope (SEM). The microscopic analysis confirmed the greater abundance of particulate on 19th Nov in the filters collected in the two observatories. Moreover, qualitative analyses by Energy Dispersion System (EDS) allowed to identify different components: fragments with irregular shape and silicatic composition, heterogeneous agglomerates of minerals and glass, and, above all, sulphur- rich minerals (mainly gypsum). Halite crystals and lime fragments, also occurring in the particulate of other days, can be attributed to sea spray and factories respectively, while the other components suggest a volcanic origin. In particular the great abundance of sulphates indicates a direct sublimation from the sulphur-rich volcanic plume. It is worth noting that in the same day in which the anomalous PM10 concentrations were registered in Lamezia Terme and Lecce, no solid deposition of volcanic ash was observed in the same areas. On the contrary, during different volcanic episodes at Mt Etna in the same period (e.g. 23/11/2013) a great amount of ash covered the Southern sector of Calabria, but no increase in the amount of atmospheric particulate was observed. This may evidence that, leaving from the eruptive center the volcanic plume decoupled into a solid-rich fraction, with large aerodynamic diameter, deposited relatively close to the vent, and an emission rich in finer aerosol fraction and gaseous precursor travelling higher distances. Minor peaks in PM10 concentrations were observed in the month of August 2014. Studies are in progress to understand if they can be related to the activity of Etna and/or Stromboli, both erupting in that period.

Sedimentation of Long-Lasting Wind-Affected Volcanic Plumes: the Example of the 2011 Rhyolitic Cordon Caulle Eruption, Chile

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Sedimentation processes and fragmentation mechanisms during explosive volcanic eruptions can be constrained based on detailed analysis of grain-size variations of tephra deposits with distance from vent and Total Grain-Size Distribution (TGSD). Grain-size studies strongly rely on deposit exposure and, in case of long-lasting eruptions, can be complicated by the intricate interplay between eruptive style, atmospheric conditions, particle accumulation and deposit erosion.

Due to these limitations, tephra deposits which allow detailed characterization of both the source term and the deposition mechanisms are a few. The 2011 Cordón Caulle eruption (Chile) represents an ideal laboratory for the study of long-lasting eruptions thanks to the good deposit accessibility in medial to distal area. After about 41 years of repose, the Puyehue-Cordón Caulle volcanic complex erupted again on June 4th, 2011, from a system of vents located about 1500 m above sea level on a NW-SE fracture of the Cordón Caulle system. The eruption caused the evacuation of 4'000 people in Chile and, due to the prevailing winds, widespread disruption to various economic sectors and human activities in Argentina. It developed as a rhyolitic long-lasting eruption with plume heights between 8-12 km during the first 3-4 days, 4-9 km during the following week and <6km after 14th June.

The whole Cordón Caulle eruption was strongly affected by wind, with only the first plume on June 4th being classified as subplinian, while the rest of the eruption being small-moderate with cumulative volume of the first 3-4 days characterized by a Volcanic Explosivity Index (VEI) 4-5.

Thirteen layers were identified in the field, correlated and organized into four Units based on lithological characteristics, grain-size features and discontinuity surfaces. All layers analysed are mostly characterized by bimodal grain-size distributions, with both the modes and the fraction of the coarse sub-population decreasing rapidly with distance from vent and those of the fine sub-population being mostly stable. Due to gradually changing wind direction, the two sub-populations characterizing the deposit of the first two days of the eruption are asymmetrically distributed with respect to the dispersal axis. The TGSD of the climactic phase is also bimodal, with the coarse sub-population representing 90 wt% of the whole distribution. We show how polymodality of individual samples is related to size-selective sedimentation processes, while polymodality of TGSD is mostly related to the complex texture of the most abundant juvenile clasts. The most representative TGSD could be derived based on a combination of the Voronoi tessellation with a detailed analysis of the thinning trend of individual size categories. Finally, a preferential breakage of coarse pumices at impact with the ground was evinced from the study of particle terminal velocity.

The last Vesuvius Eruption on March 1944: Magma Evolution and Eruptive Dynamics

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The last Vesuvius eruption on March 1944, closed a 300 years long period of intense eruptive activity began immediately after the 1631AD sub-plinian event, and characterized by moderately explosive eruptions and effusive activity. The eruption began with a modest effusive activity (18-21 March, phase-I) and then moved on to a lava-fountains phase (21-22 March, phase II) that quickly culminated in a paroxysmal phase (22-23 March, phase III), during which the eruptive column has reached a high altitude and the ash carried by the wind has arrived in Albania and Yugoslavia at distances of about 500 km from Vesuvius; the paroxysmal phase lasted only 24 hours, as later the explosions became discontinuous and the ash cloud reached altitudes not exceeding 2 km from the crater (phase IV) [Cubellis et al., 2013].

We present a detailed geochemical study of volcanic products emitted during all stages of the eruption, including an extreme distal ash sample that was collected at the time of the eruption in Albania (Devoli) by the geologist Antonio Lazzari that was there for oil exploration. The results have allowed us to formulate a hypothesis about the mechanisms that have caused a sudden increase in the degree of explosiveness. Furthermore, through the use of a numerical model of dispersion of volcanic ash in the atmosphere and the wind speed at the time of the eruption, the maximum height reached by the eruptive column has been inferred.

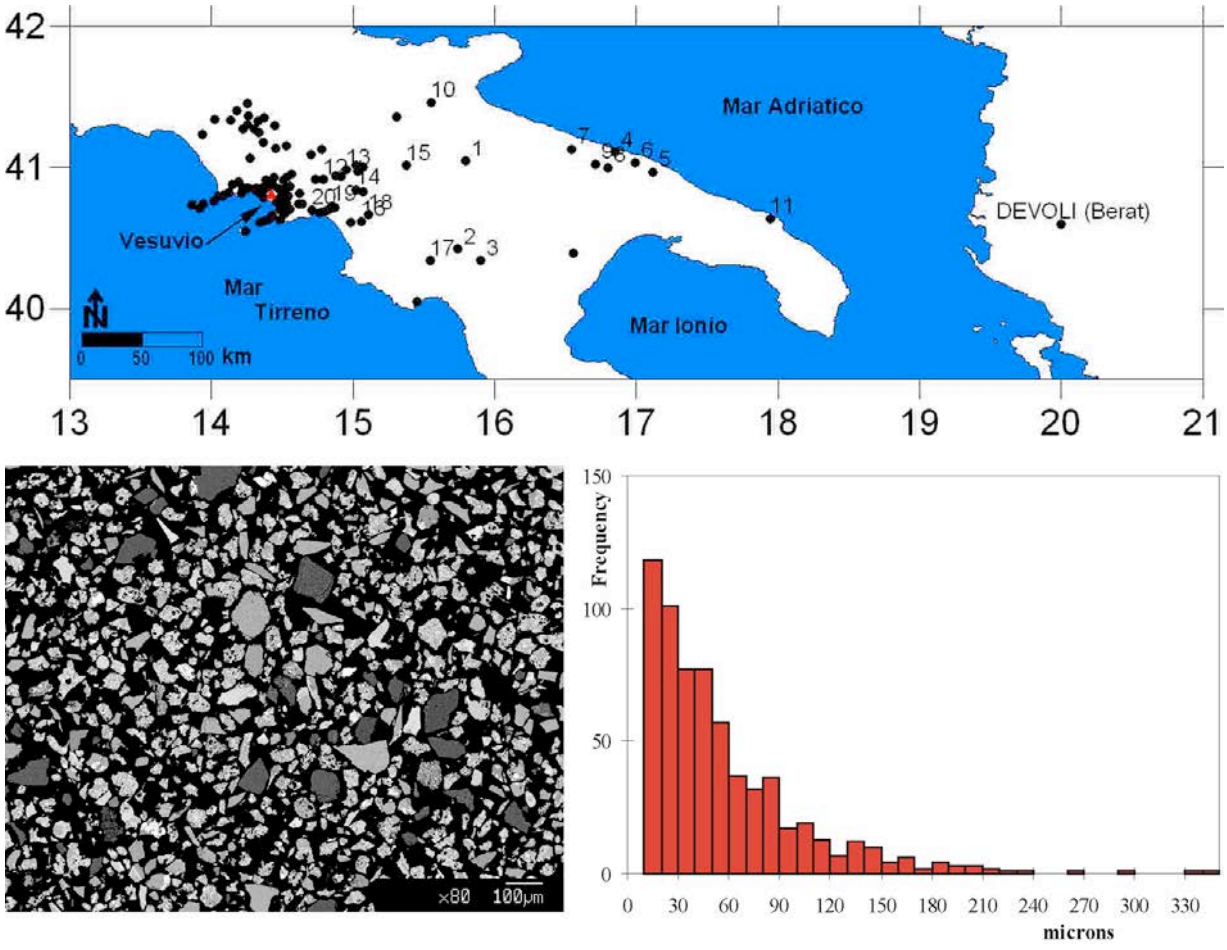

Figure 1. The map shows the sites of ash accumulation reported by eyewitness accounts (up). Backscattered image of the volcanic ash collected at Devoli in Albania (470 km from Vesuvius) and histogram of the clast size. The dimension of the clasts is between 20 and 350 microns, with a prevalence of smaller clasts (20 and 30 microns) (down).

Our data on chemical composition of volcanic rocks erupted during the 1944 eruption indicate that the magmas feeding the four phases of the eruption have similar geochemical and petrological imprints, so that the transition to the paroxysmal phase of the eruption is not related to changing in magmatic pre-eruptive conditions but instead to ascent processes in volcanic conduit. Thermodynamic calculations based on the chemical equilibrium between crystals and liquid, indicate that the magmatic differentiation would take place in two stages of crystallization characterized by different temperature and pressure [Pappalardo and Mastrolorenzo, 2010]. In a first phase of highest pressure, the cooling of less evolved magma in a crustal magma chamber (between 16 and 8 km depth), caused the crystallization mainly of olivine and diopside and to a lesser extent plagioclase, magnetite and apatite; while in the later lower pressure (depth <8 km) stage, probably associated with the ascent of magma in the volcanic conduit, mainly crystallized leucite in equilibrium with the forming more-evolved residual liquids. This process of leucite syn-eruptive crystallization in the volcanic conduit, associated with a more rapid ascent of magma, could explain the emission of magma richer in gas, and then the sudden increase of the degree of explosiveness of the eruption in the intermediate stages (II and III phase), with the emission of a greater amount of ash. By Adopting a numerical model of dispersion of ash into the atmosphere, by using as input data both the dynamic parameters of the eruption as well as the speed of the wind at various altitudes up to 12000 mt, we estimated that the eruptive column would have reached a height of at least 10 km, higher of that previous supposed on the basis of the contemporaneous studies and stories of witnesses. The event, after 70 years, is still present in the memory of people living in the Vesuvian area and in the areas invested by the volcanic ash, and the witnesses stories show that the damage and even the number of victims could be higher than accepted [Cubellis and Marturano, 2010]. Moreover the dispersion of ash over wide areas justifies the extensive loss of livestock documented by eyewitness accounts. The death of the sheep was probably the consequence of F (fluoride) poisoning (fluorosis) procured by the ingestion of grass, from pastures covered with ash. The amount of F considered lethal to grazing animals is of at least 100 µg / g of body weight (4 -5 g for animals of 40-50 kg), while values close to 50 µg / g of body weight seem to be tolerated by sheep and cattle. We have measured F concentrations between 1500 and 3000 ppm in the 1944 Vesuvius volcanic ash; with these F concentrations a layer of ash of even one mm thickness is sufficient to cause the death of the animals [Cubellis et al., 2014].

These data have strong implications on the volcanic risk. In fact, the rapid increase of the height of the eruptive column involves: 1) in the proximal area, an increase in particle size and the thickness of the pyroclastic deposits with a major impact on rail networks and collapse of roofs etc. and 2) in the distal area, an increase of the area exposed to ash fall, with repercussions on the destruction of agricultural crops over wide areas and the loss of livestock due to poisoning by fluorine, and 3) a larger amount of ash dispersed in the atmosphere with a strong influence on air traffic.

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Identifying Recycled Ash in Basaltic Eruptions

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Deposits of mid-intensity basaltic explosive eruptions are characterized by the coexistence of different types of juvenile clasts, which show a large variability of external properties and texture, reflecting alternatively the effects of primary processes related to magma storage or ascent, or of syn-eruptive modifications occurred during or immediately after their ejection. If fragments fall back within the crater area before being re-ejected during the ensuing activity, they are subject to thermally- and chemically-induced alterations. These 'recycled' clasts can be considered as cognate lithic for the eruption/explosion they derive. Their exact identification has consequences for a correct interpretation of eruption dynamics, with important implications for hazard assessment. On ash erupted during selected basaltic eruptions (at Stromboli, Etna, Vesuvius, Gaua-Vanuatu), we have identified a set of characteristics that can be associated with the occurrence of intra-crater recycling processes, based also on the comparison with results of reheating experiments performed on primary juvenile material, at variable temperature and under different redox conditions.

Understanding Caldera Unrest Dynamic for Estimation of Eruptive Potential: the Example of Campi Flegrei (Italy)

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Large calderas worldwide, which potentially can produce catastrophic eruptions, are characterized by frequent episodes of unrest, just in few cases culminating with eruptive events. This ambiguous behavior is generally explained in terms of magma intrusion or disturbance of geothermal fluids in the shallow crust, which are both source of ground deformations and seismicity. Critical to the hazard assessment related to eruption is the estimation of depth and volume of magma reservoirs and eruptible magma. The latter can be roughly estimated by fitting surface deformation with source models. Taking into account the caldera dynamic, which is strictly associated to hydrothermal system and fluids circulation, the potential eruptible magma and thus, probable eruption, can be assessed once the fluids contribute to the observed uplift is recognized. Here we investigate on the contribution to caldera ground deformation due to disturbance in aquifers, for which is fundamental to account of appropriate physical properties of rocks, such as the permeability and surface degassing. The general importance of this problem is here showed using the Campi Flegrei caldera (Southern Italy) as case study, for which new data of rocks permeability, inferred from drilling into the volcano, are used to constrain fluid-dynamical modeling (TOUGH2®). The new calculation allows us to assess the possible magnitude of a future eruption, which, in the highly urbanized area of Campi Flegrei and neighboring, has very important impact on Civil Protection scenarios.

Eruption Dynamics and Emplacement Mechanism of the Punta Chiarito Tephra (Ischia, Italy): Stratigraphic, Sedimentologic and Petrological Data

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Volcanism in resurgent calderas is a common feature, in which areal distribution of vents, style of volcanism and chemical composition of the erupted magmas, can be strongly influenced by the local stress field induced by resurgence mechanism and dynamics. In the Ischia resurgent caldera almost all the volcanic vents of the past 5 ky are located in the lowland bordering eastward the resurgent block. The Punta Chiarito Tephra (ChT) is the sole pyroclastic deposit of this period exposed in the western sector of the island, over an area of at least 5 km^2. The ChT has been archeologically dated at the end of the 8th century b.C. as it buried a human settlement of this age.

Here we present the results of an integrated stratigraphical, sedimentological, petrological and volcanological study, carried out on this tephra.

The ChT has been subdivided in Eruption units and sub-units according to the observed sedimentological features. Clasts morphology, degree of vesiculation and sedimentary structures, analyzed both in the field and laboratory through grainsize and SEM analyses, allowed the reconstruction of the eruption dynamics, type of fragmentation, transport mechanisms and depositional processes. The variations of geometrical and sedimentological characteristics (shape, thickness, grainsize, sedimentary structures) of each unit, together with direction of provenance of ballistic clasts, were used to constrain the position of the eruption vent, presently buried under landslides.

Mineralogical, geochemical and isotopic determinations allowed the characterization of both the juvenile products and the composition of the erupted magma in the frame of the evolution of the magmatic system of Ischia in the past 5 ky.

The ChT sequence was generated by a succession of magmatic and phreatomagmatic explosions that extruded a homogeneous alkali-trachytic, well-vesicular and porphiritic magma. The eruption began with a phreatomagmatic phase, which generated the basal surge of Member A. A violent strombolian-to-subplinian eruption column formed soon after and produced the fallout deposit of Member B. In the following water entered the conduit leading to a new phreatomagmatic phase, with the emplacement of the dilute pyroclastic density currents of Members C to E. The eruption ended with the formation of a pulsanting sub-plinian magmatic column generating the fallout deposit of Member F. Lithic clasts and SEM investigations indicate a progressive increase of water-magma interaction during the course of deposition of member C and its decrease from member D to F. Sr-isotopic ratio for crystals and whole-rocks indicates that the magma batch was isotopically homogeneous and deviated its composition during the eruption, towards more radiogenic values in response to magma-water interaction.

Pyroclastic Density Currents at Stromboli Volcano (Aeolian Islands, Italy): a Case Study of the 1930 Eruption

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Pyroclastic density currents (PDC) related to paroxysmal eruptions have caused a large number of casualties in the recent history of Stromboli. We combine here a critical review of historical chronicles with detailed stratigraphic, textural, and petrographic analyses of PDC deposits emplaced at Stromboli over the last century to unravel the origin of currents, their flow mechanism and the depositional dynamics. We focus on the 1930 PDC as they are well described in historical accounts and because the 1930 eruption stands as the most voluminous and destructive paroxysm of the last 13 centuries. Stromboli PDC deposits are recognizable from their architecture and the great abundance of fresh, well-preserved juvenile material. General deposit features indicate that Stromboli PDC formed due to the syn-eruptive gravitational collapse of hot pyroclasts rapidly accumulated over steep slopes. Flow channelization within the several small valleys cut on the flanks of the volcano can enhance the mobility of PDC, as well as the production of fine particles by abrasion and comminution of hot juvenile fragments, thereby increasing the degree of fluidization. Textural analyses and historical accounts also indicate that PDC can be fast (15-20 m/s) and relatively hot (360-700 °C). PDC can thus flow right down the slopes of the volcano, representing a major hazard. For this reason, they must be adequately taken into account when compiling risk maps and evaluating volcanic hazard on the Island of Stromboli.

Pyroclastic Density Currents and Topography: Modeling, Experiments and Deposits

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Pyroclastic density currents (PDCs) vary between two end members, concentrated and dilute. They are the most hazardous events of explosive volcanism, particularly when involving transformations of one end member into the other. When a PDC interacts with uneven topographies or inhabited areas, the flow velocity and density drastically change at the flow base, and this strongly affects both the deposit facies and flow impact. Here, a step-by-step integrated approach from numerical to experimental through field and observations is shown to better understand what happens during such interactions: 1) 3D Euler-Lagrange numerical simulations of column collapse are performed at tens-of-meter scale. The simulations solve for PDC velocity and density, and hence for dynamic pressure (the impact parameter of PDCs); 2) large-scale experiments of the simulated events are carried out, and the dynamic pressure is measured, in order both to validate and constrain the model. The modeled pressures agree with the experimental ones, and both agree with the values as extracted from the experimental field deposits; 3) the simulation is extended and enlarged to Vulcano Island (Italy) to study the interaction with the actual island topography. The dynamic pressures agree with the ones as extracted from the deposits at Vulcano; 4) 2D simulations over simple geometries are performed with the same model showing that massive deposits can also form by a dilute PDC against hills and down valleys, which is in agreement with the field at Vulcano, among other field examples; 5) these 2D simulations are lastly zoomed at building scale which, along with experimental evidences, shows a transverse component of the PDC dynamic pressures besides the streamwise one exerting in the interaction zone.

Volcaniclastic Sand Provenance in Magmatic Arc Setting: an Example from Lipari Island Beaches (Aeolian Archipelago, Tyrrhenian sea)

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In this study, 24 modern volcaniclastic beach sand samples, from Lipari, one of the volcanic Aeolian Islands of southern Italy, were petrographically characterized, focusing on the role of processes controlling the composition of the volcaniclastic detritus, including bedrock sources. Several distinctive types of bedrock, in the drainage basins, that are the likely prominent sources for sand at each sampled beach were recognized, and divided into two categories of provenance lithotypes: lavas and pyroclastic rocks ranging in composition from basaltic andesitic, to andesitic, to rhyolitic. Using the Gazzi-Dickinson point counting method, lithic volcaniclastic petrofacies were defined. On QmFLt ternary plot, medium- and fine-sized sand compositions from Lipari beaches overlap although finer sands are richer in individual monocrystalline feldspar grains (P+K). The proportions of various types of volcanic individual grains and lithic groups components in the medium and fine sand identified more distinct relationships between sources. Volcanic lithic fragments from Lipari beach sand, in the coastal stretch from Acquacalda to the north and the south western side of the island (Valle Muria), consist of colorless and black glassy volcanic fragments with lathwork, felsitic, vitric and microlitic textures. Moreover, high amounts of detrital unstable minerals such as pyroxene, olivine and Fe-oxides, illustrate how the analyzed sands preserve the source rock(s) provenance signals in a weathering-limited erosion regime such that of the Aeolian volcanic arc. The overall composition and texture of sand is influenced by the bedrock type that constitutes the source rocks of the drainage basins. In some cases, sand composition may be determined by fragment types [i.e., lavas vs. pyroclastic rocks] that represent only a subordinate portion of the outcropping source area because of their higher Sand Generation Indices.

Finally, our results show that these lithotypes have different propensity to create terrigenous detritus, in both in terms of grain size and composition. The Sand Generation Index (SGI) of lavas is 0.9 to 12.3 times higher than of pyroclastic rocks, even if the lavas constitute a minor outcrop area of the island. In this regard, we suggest a modified SGI, detailing the Sand (S) in terms of grain size classes: in a weathering-limited erosion regime, under a Mediterranean climate, in the case of felsic to intermediate lavas the SGI is characterized by a medium (m) to fine (f) sand generation (mfSGI) whereas in the case of pyroclastic rocks the grain size of sand is in the range of very coarse (vc) to coarse (c) sand (vccSGI). Clastic contribution from pyroclastic rock outcrops such as pumice, are not found in the studied sand samples, probably because they produce gravel-size detritus or very fine sand and/or finer detritus such as silt and clay. In the future, studies of the conversion from pumice source rock to pumiceous detritus could more thoroughly document and evaluate the propensity to create gravel- or silt-sized detritus, namely if texture and composition of this source rock could be characterized by a Gravel Generation Index (GGI) or a silt generation index (SiGI).

Ash Production within a Pyroclastic Flow: Grain-Size Variations Due to Mechanical Grinding

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Pyroclastic flow deposits are generally characterized by a large amount of ash. Direct observations and stratigraphic studies suggest that a portion of the ash fraction of pyroclastic flow deposits is generated during the transport, by abrasion and collision of largest particles. Conversely, part of the fine grained particles is generally elutriated during transport of the eruptive cloud. Due to their widespread dispersal and low sedimentation rate, ash particles represent a potential risk for living beings and environment. The knowledge of the initial grain-size distribution of an eruptive mixture is of fundamental importance for estimating physical parameters, such as intensity, magnitude and style of an eruption, and represents a basic input parameter for models of column dynamics and transport. In order to study the effect of particle collision and abrasion on the evolution of the particle-size distribution of a pyroclastic mixture, and to relate the production of ash to the evolution of particles shape, we performed grinding experiments using the Los Angeles test. This apparatus allows simulating the process of particle-particle interaction/collision and consequent abrasion and rupture. Starting material consists of three samples from Vesuvius eruptions, representing three end-members in term of textural features of the juvenile material (scoriae vs pumices) and of components that constitute the flow (whole sample vs selected scoriae): VS17 was collected at a proximal site from a flow unit of the subplinian Pollena eruption (472 DC) and represents an example of coarse-grained, lithic rich, matrix supported deposit mainly constituted by scoriaceous juvenile material; C24bis is constituted by juvenile, dm-sized, moderately vesicular scoria-like bombs, selected from a proximal pyroclastic flow deposit of the Pollena eruption (472 DC); while sample VSM80-81 is constituted by cm-sized, highly vesicular pumices from the fallout deposit of the plinian Mercato eruption (8000 yr BP). Three cycles of mechanical grinding were performed on each sample, with a duration of 3, 10 and 30 min, respectively. After each cycle, grain size analyses of experimental products were performed and an aliquot (few grams) of the resulting material from size-classes between -4 and 2 phi collected for morphological studies. In this way, the variation of the shape of the clasts and times of abrasion (roughly corresponding to the runout of the flow) can be correlated. Data are discussed in terms of enrichment in fine grained material with respect to untreated samples, revealing a strong effect of grinding duration and, surprisingly, only a minor control of material properties. Large amounts of ash are produced in the range 3 to 10 phi, with a net increase inside the smaller sizes of up to 2000%. Shape analysis were performed on a subset of 30-50 clasts from each size interval between -4 and 2 phi collected at the end of each experimental run. As good shape descriptors we consider the excess perimeter (ΔP) and defect area (ΔA), which well account for the fractured/angular (large ΔP and small ΔA) and lobate/rounded (large ΔA and small ΔP) shapes. As we could expect, clast roundness well correlates increasing experimental time with the most of the shape variation occurring immediately after short times of grinding. Grain size and shape data are useful to recognize and quantify co-ignimbrite ash early separated from pyroclastic flows and dispersed over larger areas by different transport mechanisms.

Volcanological Facies Analysis and Stratigraphy of the Silicic Rocks of Mount Amiata Volcano (Italy)

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Since the 1960s, extensive silicic sheets have been the object of controversy over their origin, because of their volcanological characteristics typical of either lava flows or welded and rheomorphic pyroclastic rocks [e.g. Henry and Wolff, 1992]. The genetic interpretation of such kind of volcanic products has fundamental consequences on the reconstruction of eruption and depositional mechanisms. Mount Amiata is a silicic Quaternary volcano that poses the problem on the genetic interpretation of its products. Considering only the outcropping rocks, Amiata's volcanic activity can be summarized in two main phases, an older extrusion of an extensive silicic basal unit and a younger emplacement of lava domes and lava flows in the axial part of the volcano [Mazzuoli and Pratesi, 1963; Ferrari et al., 1996]. The major volcanological arguments debated on Amiata, during the last 55 years, is the occurrence of explosive eruptions and the emplacement of pyroclastic flow deposits during its activity. In particular, the lower unit (Basal Trachydacitic Complex, BTC, of Ferrari et al., 1996) was considered, into the volcanological and petrochemical literature, as either a unique sheet of ignimbrite and rheoignimbrite deposits or a sequence of lava flows [e.g. Marinelli, 1961; Mazzuoli and Pratesi, 1963; Ferrari et al., 1996; Cristiani and Mazzuoli, 2003].

We present the results of a new geological field survey supported by volcanological facies analysis of the Amiata volcanics. The field analysis was corroborated by the correlation with stratigraphic and petrographic data of a deep well drilled on the southern flank of Amiata by Regione Toscana in 2010. This drilling has intersected the entire volcano sequence and reached the non-volcanic substratum showing volcanic units older than the outcropping rocks.

The geologic mapping was performed onto lithostratigraphic and synthemic procedures and allowed to distinguish two Synthems that are separated by a major unconformity surface representing an important quiescence period accompanied with pene-planation of the landforms and pedogenetic alteration of the volcanic deposits. We partially correlate our lower Synthem to the basal unit of the literature (BTC), and subdivide it into several lithostratigraphic units, defined by facies analysis, petrography and geometric features.

The following observations can improve our understanding of the eruption and emplacement mechanisms of silicic rocks of Amiata volcano.

The core succession is indicative of a rapid aggradation of effusive products >500 m thick and does not evidence pyroclastic deposits and mega-breccia facies.

The previously undivided, extensive basal unit comprises different, individual, superposed silicic lobes, in which we distinguish structural and morphological features typical of lava flows, such as basal and top autoclastic breccias, front structures and lateral termination.

The silicic rocks succession is not indicative of an "ignimbrite cycle" that overall comprises basal and final pyroclastic fall-out and surge deposits imbedding a major flow body. Moreover, interlayered tuffs are not recognized along the whole volcanic succession.

Both at microscopic and macroscopic scale, the rock texture is not fragmental.

Individual flow unit does not show evidence of facies variations from proximal near vent (e.g. co-ignimbrite lithic breccia) to distal areas of deposition that is typical of pyroclastic flow deposits.

In the individual flow unit, where is not vertical and/or lateral gradation in welding character from non-welded, to medium grade (with sparse welded zones) to pervasively rheomorphic textures.

Individual flow units are of small volume and extension, and show channelized lobe geometry.

On the basis of the discussion of these volcanological observations, corroborated by field evidences and petrographic analysis, we suggest that the extensive silicic basal (outcropping) unit of Amiata volcano is a sequence of lava flows with a rapid aggradation.

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SESSION 3

Dynamics of Magma Ascent and Evolution

Primary Magmas, Fractionation Modelling and Mantle Source of Etnean Lavas

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Mt. Etna is the highest European Volcano and one of the most active in the world. For this reason the investigation of the deep and shallow feeding system of Mt. Etna, and subsequently of his mantle source could give us some information about the eruptive style thus helping to predict future volcanic events. In this respect the complete evolution of Mt. Etna magmatism was considered performing a detailed sampling from Tholeiitic to Recent Mongibello periods.

Backward mass balance fractionations were used to reconstruct the primary composition of Etnean magmas and get some inferences on the petrological composition of their mantle sources. The Tholeiitic suite did not necessitate a backward reconstruction for the presence of real primary un-fractionated compositions. To reach the most evolved terms the involvement of 27% Ol, 14% Cpx, 29% Opx, 15% Plg and 15% Cr-Sp for a total amount of 53.1% of gabbroic material is inferred.The least differentiated products for each alkaline period were identified and about 17 to 19% of a solid assemblage made up of Ol (87 to 100%) and Cpx (up to 13%) was added to re-equilibrate the basalts with mantle olivine (Fo_{87}). A further subtraction of an average 23.3% of a solid assemblage constituted by Ol (7-18%), Cpx (26-55%) and Plag (21-48%) is needed to get to the most differentiated erupted lavas. Taking into account the volume of the erupted magmas this modeling can be used to evaluate the quantity of material intruded below the volcano edifice. On average an estimation of about 40% of material should be considered beneath it. Thus if according to [Neri and Rossi, 1992] the whole volcano edifice amounts to about 370 km^3, about 150 km^3 of magma should be left behind by the magma on its way from the mantle to the surface.

Calculated major element compositions of the primary magmas are well comparable with those obtained by melt inclusions study, while reconstructed trace element patterns fit well with those reported in the literature. These compositions are also similar to those found in the Iblean Plateau although Etnean alkaline lavas appear enriched in K, Rb, Th and U and depleted in Ti, Y and Yb. Partial melting models were developed for each Etnean magmatic period, based on a mantle composition similar to that of the nearby Iblean lithosphere. Results indicate two different sources for Tholeiitic and Alkaline suites analogously to the modeling developed by [Beccaluva et al., 1998]. Tholeiitic magmas can be reproduced by about 17% of partial melting of an amphibole-bearing peridotite source, while alkaline magmas can be reproduced by melting of about 7% an amphibole-phlogopite-bearing peridotite source. Our result are in agreement with those recently advanced by [Correale et al., 2014] indicating a large similarity between Mt. Etna and Mt. Iblei mantle sources.

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Factors Controlling the Transition from Strombolian Explosions to Lava Fountaining at Mount Etna: a Mass- and Energy-Constrained Model from the 2013 Paroxysmal Activity

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A multidisciplinary approach based on image analysis of seismic signals, thermodynamics and mass balance has been here adopted to find quantitative relations between magma degassing at depth and the transition from Strombolian activity to lava fountaining for a set of paroxysmal eruptions occurred at Mt. Etna volcano in March-April 2013.

The image processing of the seismogram allows handling of a huge quantity of data, providing a tool for the simple extraction of numerical values. We propose a model based on the consideration that gas outbursts are a vehicle of the transfer of energy tracked by seismic signals during the uprising of magma. Thus, the simple assumption of a relation of proportionality between the energy of the seismic signal and the mass of exsolved gas allows us to interpret transitions of the eruptive style as due to the amount of undegassed magma recharging the feeding system. Changes of this recharge rate in the range of 1:20 control the evolution of the eruptive process, and are evidence for the limited area section of the feeding conduit. Being this transition process observed in volcanic regions worldwide, the model can be successfully applied to other basaltic volcanoes. Furthermore, the image analysis technique may be applied to other contexts in which the interpretation of seismograms is necessary.

From Deep to Shallow: Increasing Melting Rates, Short Residence Times and Recycling of Crystal Mush-Derived Melts Revealed by U-series Disequilibria at Stromboli Volcano

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The presence of crystal mushes in the feeding system of active volcanoes is generally revealed by antecrysts, representing the crystalline portion of old magmas recycled in the juvenile material, but very little is known about the fate of interstitial liquid hosted within the crystal-rich mush (i.e. antemelt). U-series disequilibria measured in magmas erupted in the past 18 years at Stromboli volcano provide the first geochemical evidence of the involvement of antemelt and help constraining the timescales of the processes occurring in the plumbing system of the volcano. Despite almost constant major and trace element composition, significant variations in isotope ratios are observed. (^{230}Th/^{232}Th) decreases with time, whilst (^{238}U/^{232}Th), (^{226}Ra/^{230}Th) and ^{87}Sr/^{86}Sr are different in the two types of magma erupted. Magma with low phenocryst content (lp) is erupted as pumices during paroxysm and is thought to belong to a deep reservoir. Highly porphyritic magma (hp) is erupted during the normal "strombolian" activity as scoria and during the effusive events as lavas, and it is considered to derive from the former one within a shallow reservoir through degassing-driven crystallization, mixing and incorporation of antecrysts. The distinct (^{238}U/^{232}Th) of lp and hp magma requires the involvement of a component with high ^{87}Sr/^{86}Sr and (^{238}U/^{232}Th) deriving from older magmas erupted earlier in the volcano history (up to 2.5 ka). The incompatibility of U and Th in major mineral phases limits the possible effect of antecrysts, hence requiring the involvement of a U- and Th-rich antemelt. The decrease of ^{226}Ra-excess from lp to hp magmas provides further and independent evidence for the involvement of a few thousands years old antemelt.

The variation with time of (^{230}Th/^{232}Th) within lp and hp magmas is exploited to constrain the residence time of magmas in the deep and shallow reservoir of the volcano to < 55 years (inferred reservoir volume < 0.5 km^3) and 2-10 years (inferred reservoir volume 0.02-0.09 km^3), respectively. Our results show the occurrence of magmatic processes operating at different timescale within the feeding system of a so-called steady state volcano, such as Stromboli. We show that, while most of the magma is erupted within few years, a portion of it, made of both crystals (antecrysts) and residual liquid (antemelt), can be stored in the plumbing system for thousands of years to be eventually rejuvenated and mixed back into the shallow reservoir. The presence of antemelts may also affect the eruptive mechanism by promoting heat transfer in locked crystal mushes, hence favouring their remobilisation.

In addition the impressively smooth time-related variation of (^{230}Th/^{232}Th) in lp products during from 1997 to 2007 may provide a link between processes occurring at depth and at the surface. Mantle melting models show that the decrease in (^{230}Th/^{232}Th) reflects an increase in the melting rate of the mantle source beneath Stromboli. Notably, this variation can be directly related with the increase in eruption rate estimated from the volcano morphology and erupted volumes, but also from the observed increase of major explosive events and lava flows, that continues up to the present days with the latest effusive event of August 2014. We suggests that U-series disequilibria, and (^{230}Th/^{232}Th) in particular, may represent an important tool to estimate the rate of magma production and then possibly forecast the eruption rates in basaltic volcanoes such as Stromboli.

Hydrothermal Alteration of Xenoliths from Miocene Tuff Breccias from Valle Guffari (Sicily-Italy)

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Phyllosilicates occurr as replacements of olivine, clinopyroxene and interstitial materials as well as veins or fracture-fillings in hydrothermally altered basalts. The parageneses of phyllosilicates generally change systematically with depth and with the degree of alteration, which in turn is related to permeability of basalts. Minimal alteration in the basalts is characterized by the occurrence of saponite mixed-layer chlorite/smectite at low-temperature, and of serpentine, mixed-layer chlorite/corrensite or mixed-layer talc/chlorite at high-temperature. Moreover, variations in composition of hydrothermal fluids and precursor minerals, especially in Si/(Si+A1) and Fe/(Fe+Mg) ratios, are important factors in controlling the parageneses of phyllosilicates. Detailed characterization of phyllosilicates in terms of phase assemblages (parageneses), paragenetic sequences, and their compositions and microstructures may provide insight into the nature of submarine hydrothermal systems, convection and evolution of hydrothermal fluids, alteration mechanisms, and hydrothermal sulfide deposition. In ultramafic xenoliths, phyllosilicates are major products of hydrothermal alteration.

Xenolith rich outcrops were found within the Miocene tuff breccias from Valle Guffari. This locality is situated in the Hyblean Plateau (south-eastern corner of Sicily, Italy), which consists of a thick Meso-Cenozoic carbonate sequence and of Neogene-Quaternary open shelf clastics with interbedded volcanic basic rocks. On the basis of petrographic and compositional featurs, collected xenolith population may be divided into: a) ultramafic, which consist of spinel facies peridotites and pyroxenites; b): feldspar bearing suite, mostly represented by metabasite rocks and anorthosites [Atzori et al., 1999; Punturo et al., 2000; Punturo, 2010]. Moreover, Manuella [2011] reports mineralogical investigations on some Hyblean harzburgite xenoliths, which show serpentinization and related secondary minerals (i.e. sulphides, saponite). In this contest, the purpose of the present work is to describe the formation of phyllosilicates [Catalano et al., 2014] obtained from xenoliths from Miocene tuff breccias exposed to various hydrothermal conditions: temperature, 300–600 °C; pressure 0.5-2 kbar; duration of treatment 4-16 days; pH 5 - 7. Xenoliths were characterized in detail before being used as starting material in hydrothermal synthesis. The starting material and run products were characterized by X-ray powder diffraction (XRPD), scanning electron microscopy with an energy-dispersive spectrometer (SEM/EDS) and differential scanning calorimetry (DSC) and thermogravimetry (TG).

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Mount Etna 2011-2013: Three Years of Paroxysmal Eruptions Reveal the Complex History of Magma Storage, Transfer and Recharge at the Volcano

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Volcanic rocks erupted during the 2011-2013 paroxysmal sequence at Mt. Etna volcano have been investigated through whole rock geochemistry and in situ microanalysis of mineral phases. All the volcanic rocks analyzed are K-trachybasalts and show evidence of variations of the evolutionary degree through time looking at either major or trace elements. Geochemical characteristics of the volcanic rocks emitted during the 2011-2013 at the New South East Crater match those of the products erupted after 1971, for their progressively enriched potassic character and for some incompatible trace element ratios (e.g., Rb/La), with major resemblances to those of the post-2001 lavas. This suggests that magmas feeding the paroxysmal activity of 2011-2013 inherited a deep signature close to that of the post-2001 products, very comparable in particular to that of the 2007-2009 volcanic rocks for what concerns their trace element concentrations.

Also data obtained on plagioclase, clinopyroxene and olivine, which are phases sensitive to differentiation processes, show respectively fluctuations of the An, Mg# and Fo contents during the considered period. Changes through time of the anorthite content in plagioclase, Mg# in clinopyroxene and Fo in olivine can be accounted for modifications of the physical and chemical equilibrium of the magmatic system, with increase of these key parameters that is generally indication of replenishment by more basic magma and consequent mixing.

The role of differentiation processes has been evaluated through MELTS simulations. Differentiation controlled by crystal fractionation was simulated taking into account the average whole rock composition of the most basic products of the 2001-2013 activity (the 2007 volcanic rocks and the early products of 2012). Runs have been conducted in order to fix reliable chemical (fO_2 and H_2O contents) and physical (P, T) constraints of the system able to reproduce a mineral assemblage consistent with that observed from petrography. Temperature has been set between 1120°C (deep intratelluric conditions) and 1080°C (at the vent). The pressure range has been fixed between 250 and 60 MPa, which simulates differentiation occurring from ~8 km up to ~1.5 km below the summit craters. Oxygen fugacity was set at the QFM buffer. Under these conditions, most of the trends defined by major elements are justified through crystal fractionation, except TiO_2, CaO and K_2O. A recharging model has been therefore taken into account to explain their deviations, although they persist even after the modeling. These persistent divergences could be ascribed to minor differences between the petrographic characters of the erupted products and the theoretical mineral assemblage removed from the system (MELTS simulations). A further mass balance calculation has been applied by adding 9.5 vol.% of total solid into the system, which is consistent with the real quantity and composition of the mineral assemblage observed in the erupted products. This leads to the best fit between the modeled liquid and the 2011-2013 compositions.

Our modeling supports the idea that the geochemical variability of the 2011-2013 volcanic rocks is the result of superimposition of differentiation processes primarily ruled by crystal fractionation and progressive substitution of the residing magma through recharge by more basic magma. Various types of evidence suggest that the pulsating magma transfer from the intermediate (2-6 km b.s.l.) to the shallow (1-2 km a.s.l.) portions of the plumbing system could be considered the triggering mechanism of the paroxysmal activity. Also the transient eruptive behavior observed during the 2011-2013, with compositions modified by replenishment of small batches of basic magma but with geochemical signatures maintained fairly constant within a restricted range, probably reflects this style of magma transfer at crustal levels.

Investigation on the Lava Fountain Events Occurred at Etna between 2011 and 2013

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Lava fountaining events at Mt. Etna are an exceptional activity, normally preceding major flank eruptions, such as those occurred on 2001 and 2002-2003 [Calvari et al., 2001; Andronico et al., 2005]. However, between January 2011 and December 2013, 44 such events occurred at the summit of the South-East Crater, and no major flank eruptions have followed yet these episodes. Bonaccorso and Calvari [2013] explained this apparent paradox with the balance between supplied and erupted magma, that has been found steady at Etna volcano during the last 30-40 years [Harris et al., 2011]. This balance can be achieved either through few, long lasting effusive phases, or through several frequent high-output rate lava fountainings [Bonaccorso and Calvari, 2013].

The 44 lava fountaining episodes occurred between 2011 and 2013 can be distinguished into three main phases, separated by two eruptive pauses of ten and six months, respectively.

Figure 1. Visual image recorded by the fixed monitoring camera located South of Catania and at a distance of more than 26 km from the summit craters showing the great explosive cloud produced by the 23 November 2013 paroxysm.

The first phase lasted between 11 January 2011 and 24 April 2012, and comprised 25 lava fountain events displaying similar features, such as duration of the strombolian phase preceding the paroxysmal episode (hours to days), duration of the lava fountain (hours), maximum height of the fountain (~800 m), extension of the lava flow field associated to the explosive event (~4 km), and erupted volume of pyroclastics and lava flows [mean representative value of 2.5 x 10^6 m3; Bonaccorso and Calvari, 2013]. After an eruptive pause lasting ten months between April 2012 and February 2013, a second phase of lava fountaining activity resumed again in February 2013, producing 13 additional episodes until 27 April 2013 with similar features. The eruptive activity stopped six months and renewed again at the end of October 2013, producing a third phase composed by six additional episodes until the end of the year. This last phase started on 26 October 2013 with an exceptional episode during which also the North-East Crater produced an ash column that flanked the eruptive column of the South-East Crater [Del Negro et al., 2014]. This last

phase showed different characteristics and also comprised both the lava fountain with the longest duration (about ten hours on the 11 November 2013 event) and, on 23 November 2013, the most explosive end-member of the series [Bonaccorso et al., 2014], a very short but violent paroxym that produced an exceptionally high lava fountain of over 2.5 km (Figure 1), that was the only one that did not produce lava flows.

Several recent studies investigated on single lava fountain episodes [Bonaccorso et al., 2011, Calvari et al., 2011; Gouhier et al., 2012; Bonaccorso et al., 2013a] or on more events inside a single eruptive phase [Ganci et al., 2012; Bonaccorso et al., 2013b]. In this paper we investigate the volcanological characteristics (duration, column height, effusion rate, emitted volume) of the complete 2011-2013 lava fountains series, also supporting the study with the information coming from the visual and thermal images of the cam network and the strain changes recorded by the two deep borehole strainmeters network working on Etna.

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The Deep Plumbing System of Mt. Etna: Temporal Evolution Detected by the Study of Sub-Aphyric Primitive Magmas

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Mt. Etna sub-aphyric primitive magmas are erupted during rare and highly explosive flank eruptions which were firstly called eccentric by Rittmann [1965], and have been recently renamed DDF, i.e. deep dyke-fed eruptions by Corsaro et al., [2009]. These eruptions are uncommon in the history of Mt. Etna but occurred both in historical (1763, 1974, 2001 and 2002-2003 eruptions) and pre-historical times (from 15ky to 3540y; eruptions of Mt. Spagnolo, Mt. Frumento delle Concazze, Mt. Maletto and 3930 BP FS Mg-rich tephra).

DDF eruptions are driven by deeply-rooted magma intrusions which rapidly ascend and bypass Etna shallow plumbing system. Hence the composition of the DDF-related magmas is poorly modified by pre-eruptive magmatic processes (i.e. fractional crystallization, mixing etc…). Accordingly, these eruptions represent a promising tool to investigate the dynamics of the volcano deep plumbing system and the mantle or mantle-crust interface processes.

We combined a complete dataset (petrology, major and trace element geochemistry) on newly collected samples from six known DDF eruptions with the literature data that allows us to decipher significant compositional changes of DDF magmas over the last 15 ky. This chemical evolution, which is not progressive but recurrent, is consistent with long-term magmatic processes involving different melting degrees of the source region and variable contributions of slab-derived components. Furthermore, short-term compositional variations have been documented also within the products of Mt. Frumento delle Concazze and attributed to local processes, such as fractional crystallization occurring in the deep storage region of the plumbing system.

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The Episodic Eruptions of South-East Crater from 2000 to 2014: a Tool to Investigate Magma Dynamics of Summit Eruptions at Etna

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The South-East Crater (SEC) is one of the four summit craters of Mt. Etna and the most active during the last decades. In particular, between January 2000 and December 2013 it was the site of four 'episodic eruptions' characterized by the occurrence of powerful lava fountains, generally associated with the emission of lava flows. The most striking of these eruptions was the first, which occurred in 2000 (64 episodes from January to June 2000); the second consisted of 7 episodes which lasted from March 2007 to May 2008, the third occurred from January 2011 to April 2012 (25 episodes) and finally, 19 episodes took place from February to December 2013. Starting from January 2011, paroxysmal activity determined significant morphological and structural change of the summit area of the volcano, leading to the construction of a new pyroclastic cone on the eastern flank of the SEC, i.e. the New South-East Crater (NSEC), which presently is the active crater.

The four episodic eruptions are different for the volcanological features, i.e. the whole period of activity, energy, frequency and duration of single episodes, as well as for the volume of erupted pyroclasts and lava flows. The punctual and detailed sampling which has been performed for most of the eruptions, allowed us to analyse the petrographic and compositional features of magma feeding the episodic activity of the SEC and the NSEC. Data show long-term variability of major and trace elements in bulk rocks which is mostly controlled by a mixing processes between a fairly evolved magma stored in the shallow plumbing system, and a recharging more primitive magma ascending from depth.

Focusing on the short-term variability, the frequency and entity of deep magma recharge, the variable proportions of magmas which mix, the dynamics of gas-magma mixture in the reservoir and also the occurrence of tectonic accidents, are important factors which may influence not only the paroxysmal activity, but also the transition from episodic summit activity to flank eruptions, as it occurred for the 2008-09 flank activity, which took place just three days after the conclusion of the 2007-08 episodic activity at the SEC.

Tephra Layers as a Stratigraphic and Chronologic Tool: an Example from Marine Cores of Central Mediterranean Area

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In this work are shown preliminary results about a tephrostratigraphic study carried out in marine cores sampled in Ionian and Tyrrhenian seas.

Twelve gravity cores were collected offshore the eastern margin of southern Tyrrhenian coast and the Taranto Gulf in the Ionian Sea during a cruise of the R/V Urania (sponsored by CNR of Italy). The cores were drilled at water depths between 76m (CD02) and 995m (GT2) and are between 0,80 to 5,30 m long. The sampled hemipelagic deposits contains several cryptotephras and, at present, five cores were sampled for tephra layers: GT2 and GT4 (Taranto Gulf), D1 and P1 (Policastro Gulf) and GS1 (Salerno Bay). EDS analyses were carried out on fresh volcanic glasses and mineral phases at Dipartimento di Scienze della Terra of University of Pisa and at Dipartimento di Biologia, Ecologia e Scienze della Terra of University of Calabria. Chemical compositions of deposits were compared with those of the main Holocene eruptions of italian volcanoes (Campanian Volcanic Zone, Eolian Islands, Mt Etna, etc...) and with similar tephras recently recognized in both continental and marine archives (Lago Grande di Monticchio, Sulmona Basin, Ionian Sea and Balkans). Most of analyzed cryptotephras, when plotted on Total Alkali vs. Silica diagram, show a phonolitic composition, while the remaining tephra layers have variable compositions. In most cases analyzed tephras were correlated with the Holocene activity of Somma-Vesuvius, Campi Flegrei, Eolian Islands and Mt. Etna. These preliminary correlations confirm and improve the previous assessed dispersal areas of the pyroclastic products of recognized eruptions allowing us to define new hazard evaluations about these important volcanic centres of central Mediterranean area. The correlation of a minor number of tephra layers remains doubtful. These data highlights how the dispersal of ash in the atmosphere allows the correlation of geologic archives sometimes over distances up to several hundreds of kilometres.

Magmatic Processes Revealed by Textural and Compositional Features of Large Anorthoclase Crystals from the Lajes-Angra Ignimbrite (Terceira Island, Azores)

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Lajes-Angra Ignimbrite (LAI) is the most recent (around 21 ka) caldera-forming event produced by Pico Alto volcano at Terceira Island (Azores). Lajes-Angra Ignimbrite Formation comprises two members closely spaced in time: Lajes and Angra. The Lajes member, the most widely distributed throughout the island, was sampled at two sites: 1) at Lajes (type location), in the northern part of the island, where the succession is characterized by a thin crystal-rich basal layer (TERS 17.1) overlaid by a fine-grained welded lapilli-tuff layer and an upper partially welded coarse clast-bearing layer (TERS 17.2); 2) at São Mateus, in the south coast, where the upper layer of the succession is also partially welded (TERS 62.1). Juvenile clasts are comenditic-trachyte in composition and coarsely porphyritic, ranging from highly vesicular pumice to dense vitrophyric clasts. Mineral assemblage mainly consists of anorthoclase (Ab_{64-70}, An<7 mol%), and less abundant olivine (Fo_{28-45}), clinopyroxene ($En_{60-80}Fs_{20-40}$), ilmenite and magnetite. Phenocrysts of anorthoclase range in size from < 2mm in the crystal-rich basal layer, up to 4-5 mm in the partially welded upper layer. We found that, except for the basal layer, in the other two samples, large crystals of anorthoclase include pockets of highly vesicular melts (fig.1a). Large crystals with similar textures are quite common in trachytic magmas at Pantelleria and in other silicic magmas. In addition to vesicular glass, these crystals also include vesicles not rimmed by glass. The borders of glassy pockets can be both smooth and angular, and usually marked by a line of Fe-rich melt. This melt is enriched in elements that are not admitted into anorthoclase (Ca, Fe, Mg, Ti) and depleted in Si, Al, K and to a lesser extent in Na. The vesicular glass in the pockets is a comendite-trachyte with composition quite similar to that of the matrix glass. Despite the large phenocrysts appear compositionally homogeneous at SEM, the cathodoluminescence imaging spectroscopy reveals complex growing textures. Crystals are patchy-zoned, with resorbed cores and inclusions-free rims (100-300 μm) (fig.1b). Preliminary LAM-ICP-MS analyses of anorthoclases highlighted a large trace-element compositional variation, which is also evident at the scale of the single crystal. Our interest is to understand HOW and WHY the large glass pockets-bearing anorthoclases were formed and if they were related to dissolution or rapid growth, during pre- or syn-eruption degassing processes. Textural and geochemical data are used to obtain information on: i) the evolution of the shallow reservoir; ii) relation between magma and crystal mush; iii) syn-eruptive processes of crystallization-induced degassing. Results are discussed in terms of growth mechanisms of crystals and magma dynamics immediately before or during the eruptive event.

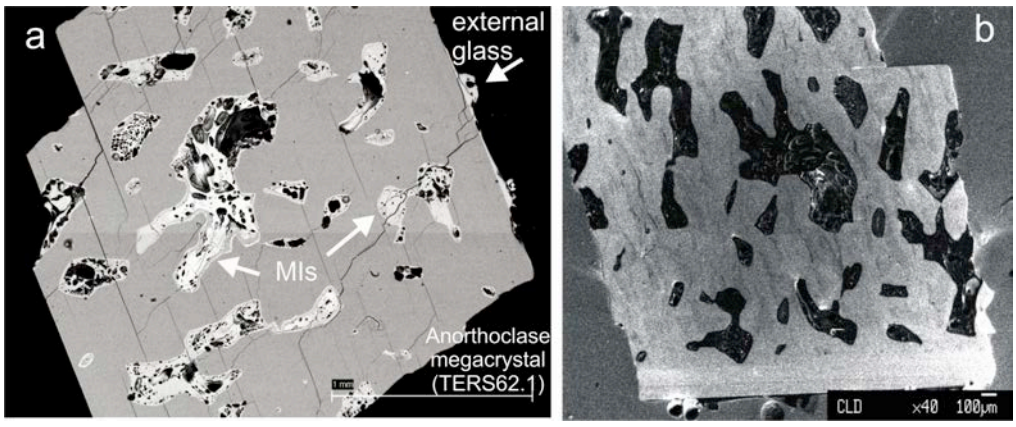

Figure 1. Fig.1 a) SEM image of an anorthoclase phenocryst with inclusions of vesicular glass. B) Cathodoluminescence image of the same crystal, showing the patchy-zoned inner core and the regular zoned external rim (200 micron).

Insight on the Recent Magmatic System of Lipari and Vulcano on the Basis of New Structural and Geochemical Data

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Recent studies, based on field and geochronological data on the available chronicles, show that in the southern sector of the Aeolian Archipelago the historical volcanic activity occurred close in time or, in some case, simultaneously at different vents along a NS tectonic alignment: in the early XIII c. at Lipari (Mt Pilato-Rocche Rosse eruption), La Fossa of Vulcano (Commenda and Palizzi eruptions) and Vulcanello, and in the XVII-XVIII c. at La Fossa (Pietre Cotte) and Forgia and, possibly, at Vulcanello. Petrochemical investigations on the erupted magmas suggest the existence of a polybaric feeding system connected to deeper shoshonitic-latitic magmas that periodically refills the shallow system. The reactivation of the shallow systems directly originates latitic-trachytic eruptions and/or is the trigger for the rhyolitic ones.

Structural data allowed to get information about the kinematic of the structures and the local and regional stress field, as well as to better understand the structural relationships among the two islands and stress regime-recent magmatism. Most of the structures have a N-S and NNW-SSE direction and in both islands a distensive regime is dominant. As a whole, structures are oriented N-S at Vulcano, and they curve at NNW-SSE in the North and South of Lipari. When they are present, kinematic indicators support a mainly normal component (pitches between 80 and 130°, indicator of dip-slip), with a subordinate strike-slip component. Structural results suggest a possible change of the stress field that could vary at a regional scale, from a pure strike-slip regime along the Tindari-Letojanni fault, to an extensional regime at Vulcano and Lipari.

Most of recent products are only marginally faulted or not faulted at all. Recognized structures may have a magmatic origin and not necessarily be related to regional systems with estimable recurrence times.

At Vulcano a key area for the understanding of tectonic deformation and its relationship with magma uplift is the M. Saraceno area where (a) the stratigraphic sequence and the volcanic structures indicate the locus of a probable recent activity, successive or coeval to the formation of Fossa caldera, and (b) faults and fracture are N-S oriented, as the structures that guided the magmatic upraise of historic activity.

A C^{14} age on coal fragments found in the upper portion of Saraceno scoriae give an age of 8890 +/- 30 BP which well fit with the previous age determination.

We also performed textural and chemical (major and trace elements) analyses on mineral phases including Sr-isotope ratios on core-rim traverses and groundmass by micro-drilling technique. At this aim, we selected the most primitive products (latitic enclaves and their hosts) from the most recent eruptions of La Fossa and the 1739-1888 and other historical eruptions of Lipari and Vulcano.

Particular attention has been devoted to latites erupted during the last activity (1888-90) and latites erupted during the post-medieval activity (Gran Cratere). They represent the most recent ascent of a relatively poorly evolved magma at La Fossa, an event that could have triggered the last eruptive phases. Results provide informations on the path of rising magmas, storage time and depth of magma chambers, pre- and syn-eruptive mechanisms and their relative timescales.

The comparison of chemical composition of the historical latites in terms of trace elements of whole rock and single minerals confirms their strong similarity. Micro-Sr isotope data analyzed on plagioclase, sanidine and clinopyroxene show a large variability (0.70460- 0.70590), also among the minerals of a same sample. Clinopyroxene cores, however, have lower Sr isotope ratios than sialic phases and show quite similar values in all the studied samples, suggesting their origin from a common magma. This characteristic seems to confirm that the same latitic magma may refill the shallower part of the feeding system. Furthermore, the higher Sr-isotope ratios of the sialic phases may suggest their crystallization at lower depth during the crustal contamination processes.

Constraining Chronology and Time-Space Evolution of Holocene Volcanic Activity on the Capelo Peninsula (Faial Island, Azores): the Paleomagnetic Contribution

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Faial is one of the most volcanically active islands of the Azores Archipelago. Historical eruptions occurred on the Capelo Peninsula (westernmost sector of the island) during A.D. 1672-1673 and more recently in A.D. 1957-1958. The other exposed volcanic products of the peninsula are so far loosely dated within the Holocene. Here, we present a successful attempt to correlate scoria cones and lava flows yielded by the same eruption on the Capelo Peninsula using paleomagnetic data from 31 sites (10 basaltic scoriae, 21 basaltic lava flows). In the investigated products, we recognize at least six prehistoric clusters of volcanic activity, whereas 11 lava sites are correlated with four scoria cones. Dating was conducted by comparing our paleomagnetic directions with relocated Holocene reference curves of the paleosecular variation of the geomagnetic field from France and the UK. We find that the studied volcanic rocks exposed on the Capelo Peninsula are younger than previously believed, being entirely formed in the last 8 ky and that the activity intensified over the last 3 ky. Our study confirms that paleomagnetism is a powerful tool for unraveling the chronology and characteristics of Holocene activity at volcanoes where geochronological age constraints are still lacking

New Insight into the 2011-2012 Unrest and Eruption of El Hierro Island (Canary Islands) Based on Integrated Geophysical and Petrological Observations

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A shallow submarine eruption took place on October 10, 2011, about 2 km off the coast of La Restinga, a small village located in El Hierro (Canary Islands, Spain). The eruption lasted about four months and ended by early March 2012. It was preceded by an unrest episode that initiated three months before, in July 2011, and characterized by more than 10,000 localized earthquakes accompanied by up to 6 cm of vertical ground deformation. This is the unique case in the world of a submarine eruption that was monitored since the unrest to the end by the monitoring network of IGN (Instituto Geográfico National), providing a huge dataset that includes geophysical (seismic, magnetic and gravimetric), geodetic, geochemistry and petrological data. These data have been here interpreted in order to present a model, which describes the intrusion and ascent of the magma. According to our model, a major intrusion occurred beneath and around preexisting high-density magmatic bodies, localized in the central sector of the island, and led to an eruption in the Southern sector of the island. After a failed attempt to reach the surface, while various dykes were emplaced, through a low fractured area in the Central and Northern parts of the island, the ascending magma finally found its way in the submarine area of La Restinga, in the South rift zone, at a depth of 350 m below sea level. Feeding of the eruption was achieved by the ascension of an important volume of material from the upper mantle which was emplaced near the crust-mantle boundary.

Double Nature Mechanism of Lava Fountain Eruptions at Mt. Etna

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During the 2011-2013 period, Mt. Etna has been affected by about 40 lava fountaining eruptions occurred at the New South East Crater (NSEC). The eruptive style was rather constant during the three years, nevertheless some differences were observed in the duration of each eruption.

Each paroxysm can be divided into 4 stages: the reappraisal of activity, the initial Strombolian phase, the climax of activity (lava fountaining) and the final Strombolian phase. The phenomenological observation allows us to recognize two main types of paroxysmal eruptions, namely long- and short-lasting events. In particular, the former eruptions show prolonged period of initial Strombolian activity (e.g., 11-12 January 2011; more than 24 hours), whereas the latter have shorter initial Strombolian phases (e.g., few hours; 18 March 2012). In order to investigate the dynamics controlling the observed duality for the same style of activity, we have studied through a multidisciplinary approach a set of 25 paroxysms occurred during the period 2011-2012, integrating data from volcanic tremor and petrology.

The time series of the amplitude evolution of the volcanic tremor (calculated by Root Mean Square, RMS) have been analyzed. As described above, the eruptive phenomena showed not constant duration of the initial phase and, consistently, the RMS patterns revealed the presence of two dominant morphologies: 1) ramp-shaped and 2) bell-shaped, which diverge in the pattern preceding the maximum amplitude values reached during the lava fountaining. The source location of the volcanic tremor centroid has been integrated for a subset of eruptions having different seismic RMS patterns. Data showed the coexistence of two sources of volcanic tremor. The former is active during the lava fountaining and is located close to the NSEC (~3 km a.s.l.), the latter is below the North East Crater (NEC) at 1–2 km a.s.l. and is evident during the Strombolian phases (initial and final) and during the rest between the paroxysmal eruptions.

In order to identify the driving force of the long-lasting eruptions with ramp-shaped RMS and the short-lasting ones with bell-shaped RMS, we have performed textural and compositional analyses (An-FeO core-to-rim profiles) on selected plagioclase crystals. Disequilibrium textures at the rims indicate the presence of two groups of crystals characterized by: 1) concordant increase of An and FeO; 2) increase of iron at rather constant or decreasing anorthite. Sudden An and FeO increase in disequilibrium zones is indication for chemical variations of the system. Discordant trends of An and FeO can be attribute to oxygen fugacity increase. The different behavior of An and FeO at plagioclase rims revealed the double nature of the recharging events that trigger the eruptions. In case of long-lasting paroxysmal eruptions, plagioclase compositional profiles prove the replenishment of the system by new, more basic and volatile-rich magma. In case of short-lasting events, the chemical evidence in crystals is consistent with recharge due to

injections of prevalent gas.

Further inferences on textures at the core and compositions of the plagioclase families put into light that the recharging magma batches can ascend throughout various pathways from the deeper to shallower levels of the plumbing system. In any case, basic magmas or transient gas bursts reach 1-2 km below the NEC, rejuvenate the residing system and remobilize the stored magma triggering the eruptions. Shifting of the activity at the NSEC confirms the existence of a shallow link connecting the activity of the North-East and the New South-East Craters.

The combination of geophysical and petrological results revealed to be an interesting approach to elucidate magma dynamics at Mt. Etna volcano. Our outstanding result is that long-lasting eruptions are driven by recharge of more basic undegassed magma that leads to gradual increase of the eruptive intensity characterized by ramp-shaped seismic RMS. On the contrary, short-lasting eruptions are controlled by transient gas bursts that produce rapid developments of the eruptive sequence and fast shifting to the lava fountaining phase, producing typically bell-shaped morphology of the seismic RMS.

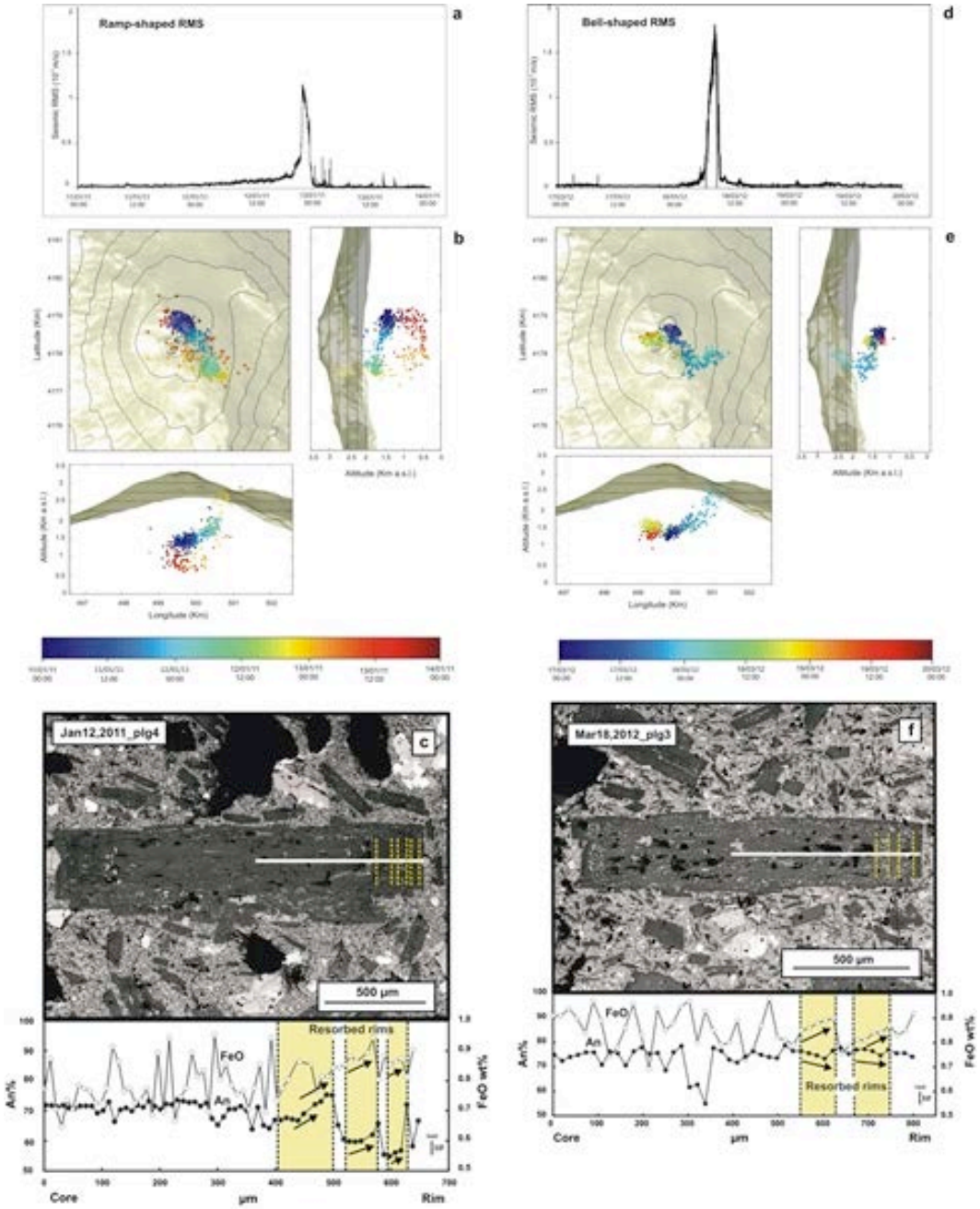

Figure 1. (a, d) Seismic RMS and (b, e) volcanic tremor source locations of January 12, 2011 and March 18, 2012 eruptions. (c, f) BSE images of plagioclase crystals and their associated An and FeO core-to-rim profiles.

An FT-IR Melt Inclusions Study in Pre-Green Tuff Tephra, Pantelleria (Italy)

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At Pantelleria island, Sicily Channel, metaluminous to peralkaline felsic magmas were erupted in a wide dynamical range: lava flows, plinian to strombolian eruptions and pyroclastic flows.

We present the results of melt inclusions study from some old eruptive units (age 190-80 ka), more precisely: six strombolian / ultra-strombolian fallout deposits and one unwelded ignimbrite. These deposits are exposed in the north-east to north-west sides of the island along coastal scars or in caldera northern inner wall, and else in the southern portion of island. These eruptive units are not correlative and the rationale of this study was to acquire the widest possible data set of pre-eruptive volatile contents in quickly cooled products (i.e. excluding all the welded ignimbrites) in order to compare with existing and growing FT-IR data obtained on the Green Tuff plinian and more recent strombolian eruptions. All the studied products are pantelleritic in composition with an Na + K/Al ratio in the range 1.2-1.7, with also a typically high content of Zr (up to 1935 ppm) and Nb (55-262 ppm).

We assessed the pre-eruptive H_2O and CO_2, measured by FT-IR spectroscopy, in 50 primary melt inclusions entrapped in anorthoclase phenocrysts. In all melt inclusions, CO_2 content is below the detection limit (i.e. < 50 ppm), while H_2O varies in a wide range (0.3 wt% to 3.7 wt%).

Interestingly, the pumice fallout deposits (fed by pantellerite magma) represent the entire spectrum of H_2O variation (0.3-3.7 wt%) clustering at 1.43±0.9 wt%. A pumice flow, that represents the highest eruptive magnitude among those studied, is characterized also by a variable H_2O content (0.7-3.3 wt%, 1.5±0.8 wt% mean value): these values are slightly but significantly lower then the Green Tuff plinian (H_2O = 1.4-4.2 wt%, 2.7±0.7 wt% mean value; Lanzo et al., 2013) but also of much less energetic young pantellerite strombolian eruptions [Gioncada and Landi, 2010]. The maximum H_2O contents translates in a confining pressure of 0.85 kb, which in turn corresponds to a depth around 3.5 km.

Compositional data do not show a clear relation between magma peralkalinity and H_2O content in studied melt inclusions.

Taking account the highest H_2O content in the studied melt inclusions (3.3 and 3.7 wt%), we may trace the following conclusions: (i) it is confirmed the hydrous character of pantellerite melts; (ii) the storage of pantellerite melts is confined to rather superficial crustal reservoirs (P < 1 kb); (iii) pre-Green Tuff low-energy eruptions are slightly lower in their H_2O content if compared to the post-Green Tuff low-energy eruptions (H_2O max = 4.3 wt%, Gioncada e Landi, 2010).

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The Intensive Variables of Mount Etna Feeding System and their Effects on Magma Crystallization and Fractionation

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The recent activity of Mount Etna can be explained envisaging that eruptions could be triggered by magma mixing or by decompression of shallow (6-4 km b.s.l.) magma batches. In such a type of feeding system, characterized by the absence of a persistent magma chamber, mixing occurs between magmas with very similar geochemical features but that underwent to different fractionation histories, constrained by the intensive physical parameters of the magmatic system: pressure (P), temperature (T), oxygen fugacity (fO_2) and volatiles content (XH_2O-CO_2).

In this contribution, we face up different aspects of the crystallization history of Etnean magmas from the mantle source to the surface, focusing on textural and compositional variations of clinopyroxene and plagioclase as a tool to record changes in the physical and chemical parameters of the magmatic system.

Oxygen fugacity (fO_2) is a key parameter of magmatic systems because it constrains the Fe^{2+}/Fe^{3+} ratio and the stability and composition of mineral phases, especially oxides. Moreover, fO_2 determines the Mg# of a melt and therefore its primitive character, which is the starting point for several petrologic considerations. We estimated the fO_2 of Etnean magmatic system with the method of France et al. [2010] and calculated the primitive magma composition by adding a wehrlite-dunite assemblage (Ol 87-100 %; Cpx 0-13%) for a total amount of fractionation (F) from 15 to 18 % to the most basic erupted magma of each volcanic sequence (Tholeiitic, Ancient Alkaline Centres, Ellittico and Recent Mongibello).

Calculation stopped when equilibrium was reached (Mg# of equilibrium olivine 88) following the Fe^{2+}/Fe^{3+} ratio of 0.15 as suggested by the determined fO_2 of QFM+1 Kress and Carmichael (1991).

Mantle equilibrated compositions were used to estimate the modal proportions of minerals in the mantle source and in the eutectic during the melting process. Mass balance calculation highlights that both tholeiitic and alkaline series can be produced by variable degree of partial melting of a lherzolitic source (in spinel facies), with a variable amount of amphibole (9-10 %) and phlogopite (0-1%). This source is perfectly comparable with that modelled for the nearby Hyblean basaltic magmas.

Temperature and pressure of the Etnean magmatic system were estimated by applying the Cpx-melt equilibrium following Putirka et al. [1996] and [2008]. Clinopyroxene equilibrium was tested on the basis of cpx-liqKdMg-Fe [Putirka, 2008]. Water content was calculated using the equation of Lange et al. [2009] on the equilibrated phenocrysts.

These parameters, together with the reconstructed primitive and a real, more differentiated, magmas from recent eruptions, were then imputed in the MELTS modelling in order to constrain the phase stability. Calculations were performed at different P (400-50 MPa, step 50, XH_2O (0-3 wt. %, step 0.5) and decreasing T from 1300°C to 1000°C (steps of 20°C). MELTS model indicate that olivine is always the first phase to appear on the liquidus, followed by clinopyroxene, magnetite and plagioclase. Increasing the amount of dissolved H_2O of about 1 wt. % lower the liquidus temperature of about 50°C for all the mineral phases.

Plagioclase stability field is strongly influenced by T, P and H_2O content. At low water content it appears on the liquidus at higher T and low P and the Albitic content increases. At high water content more anorthtic compositions are stable only at low P conditions. Textural and compositional features of plagioclase were then used to reconstruct its growth history and by consequence the variation of the intensive variables within the feeding system, such as magma inputs volatile addition, decompression and degassing.

The overall picture highlights that Mt. Etna feeding system is a vertically extended and continuous feeding system without any large magma chambers. Crystallization occurs under polybaric conditions which at least two magma ponding levels between 10-8 km b.s.l. and 6-4 km b.s.l.

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Tectonically-Controlled Magma Transfer During the 1783-84 AD Eruption at the Laki Fracture (Iceland) Inferred from Compositional and Temporal Records Preserved by Olivine Crystals

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Comprehension of relationships between regional tectonics and rates of magma ascent and eruption is among the major objectives of the recent volcanology, especially for active volcanic systems located along important rift zones either in oceanic or continental domains. In these settings, extraordinary fissural eruptions take place, which are characterized by fracturing extending for several kilometers at the surface and by emplacement of huge amounts of magma at elevated rates of emission. The fissural eruption of 1783-1784 AD at the Laki system (Eastern Volcanic Rift Zone of Iceland) is among the best examples of this activity. This work focuses on clarifying the role of regional tectonics on the onset of this long-lasting eruption.

This event represents one of the largest lava flood eruptions in the world history, involving ten fissure-opening episodes and producing about 15 km^3 of lavas and tephra within eight months of activity. Emitted lavas are tholeiitic basalts with a phenocryst assemblage constitutes by clinopyroxene, plagioclase and olivine. Crystals display no evidences of disequilibrium textures at the core or rim, thus ruling out the idea that open system processes such as magma intrusion and mixing could have occurred. Nonetheless, the observed compositional and dimensional diversity of mineral phases provide evidence of variable chemical and physical conditions of crystallization at distinct crustal levels. We used data on compositional zoning of olivine crystals to provide detailed insights on characteristics of the plumbing system beneath the Laki fracture. Distinct olivine populations have been found, characterized by core compositions at Fo_{73-75} and Fo_{77-79} respectively. Compositional features of olivines have led to the identification of at least two different magmatic environments where crystals grew and resided under near-equilibrium conditions with the host magma. Rather uniform rim compositions (Fo_{57-60}) show that all erupted olivines have experienced a common late-stage magmatic history.

Olivine zoning has been also used to constrain the timing of magma transfer throughout these different segments of the plumbing system. Modeling of the Fe-Mg diffusive re-equilibration of the olivine compositional zoning during the ascent has led to very short timescales, ranging from 6-11 days for the population with Fo_{77-79} cores to 1-5 days for what concerns the more evolved Fo_{73-75} cores. Our time estimations, in combination with textural observations that rule out the presence of pre-eruptive magmatic processes, confirm that magma ascent has been driven by the prominent role of extensional regional tectonics, which acted therefore as triggering mechanism of the eruption. The presence in a hand-size sample of distinct crystal populations implies that crystals, which have previously grown in chemically distinct magma batches, finally had the chance to mix mechanically when magma was burst rapidly from the storage zones upward to the surface.

Olivine Crystals Record Timescales of Magmatic Processes before the April 2010 Flank Eruption at Eyjafjallajökull Volcano, Iceland

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The early eruptive phase of the 2010 eruption at the Fimmvörðuháls Pass, Eyjafjallajökull volcano (Iceland), produced olivine-rich alkali basalts, whereas benmoreitic tephra were emitted during the second explosive phase from the summit vent of the volcano.

Basalts from the initial flank eruption contain euhedral or embayed olivine crystals characterized by different core compositions and zoning patterns. Three main olivine core populations have been found: i) cores with rather constant composition at Fo_{88}; ii) $Fo_{81\text{-}82}$ olivine cores with either no zoning or a slightly reverse zoning pattern; iii) only reversely zoned cores with $Fo_{77\text{-}78}$ composition.

In this study, the textural features and chemical zoning preserved in olivine crystals have been used to track the pre-eruptive history of basaltic magmas feeding the Eyjafjallajökull flank eruption. Specifically, we have obtained temporal information on magmatic processes acting beneath the volcano by modeling the Fe-Mg diffusion on the observed olivine chemical profiles. The compositional record preserved in the Fo_{88} olivine cores reveal homogeneous chemical-physical conditions of crystallization in a deep magma reservoir, followed by a subsequent re-equilibration of crystals as the magma ascended upward shallower crustal levels. The reverse zoning patterns of the core population ii) and iii) also imply the occurrence of two recharge events of mafic magma at distinct crustal depths. The retrieved timescales for olivine-melt equilibrations by diffusion range from about 30 days, for both the most primitive Fo88 and the Fo81-82 crystals, to 16-20 days for the $Fo_{77\text{-}78}$ olivines.

This array suggests that processes able to trigger diffusion in population i) and ii) started in the deep crust, where a system of compositionally zoned reservoirs could exist. This hypothesis is supported by the evidence that only part of the $Fo_{81\text{-}82}$ olivine crystals record reverse zoning as a consequence of the interaction with the most primitive and hotter magma containing Fo_{88} crystals. The time gap of about 15 days between the two recharge events implies the existence of at least an intermediate magma storage level within the crust, where the primitive basaltic magmas intrude and mix with the pre-existing and more evolved ones. Injection of the more mafic magmas in the shallow reservoir produced significant compositional changes in the residing magma, which result in reversely zoned $Fo_{77\text{-}78}$ olivine cores, finally leading to the eruption in an average time span of three weeks.

Constraints on the Nature and Evolution of the Magma Plumbing System of Mt. Etna Volcano (1991 - 2008) from a Combined Thermodynamic and Kinetic Modelling of the Compositional Record of Minerals

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We present a novel petrological approach that combines kinetic modelling of the diffusive relaxation of chemical zoning patterns in olivine crystals with thermodynamic modelling (MELTS) to constrain the nature and evolution of Mt. Etna's plumbing system and the processes governing its internal dynamics. We investigated the compositional and temporal record preserved in 180 olivine crystals that were erupted between 1991 and 2008. Detailed systemization of the information stored in the sequential zoning record of the olivines reveal the existence of at least five compositionally different magmatic environments (MEs), characterized by different olivine compositions: M0 (=Fo_{79-83}), M1 (=Fo_{75-78}), M2 (=Fo_{70-72}), M3 (=Fo_{65-69}) and mm1 (=Fo_{73-75}). Several routes of magma transfer connect these environments. We identified three prominent magma passageways between the environments M0:M1, M1:M2, and M2:mm1 that were active during the entire period of observation between 1991 and 2008. Modeling the diffusive relaxation of the olivine zoning patterns reveals that the transfer of magma along such routes can occur over fairly heterogeneous timescales ranging from days to up to 2 years. Although some of the passageways have been sporadically active in the months and sometimes years before an eruption, the magma migration activity increases clearly in the weeks and days prior to an eruptive event. In this context, major transfer routes such as M2:mm1 might represent temporary passageways that are activated only shortly before eruptive events. A forward modelling approach was developed using thermodynamic calculations with the MELTS software to identify the key intensive variables associated with the different magmatic environments. In this approach the observed populations of mineral compositions (e.g. Fo_{79-83}), rather than individual compositions, are associated with thermodynamic parameters (pressure, temperature, water content, oxygen fugacity [=fO_2] and bulk composition of melt) to identify the most plausible set corresponding to each ME. We found that temperature, water content, and possibly oxidation state, are the main distinguishing features of the different magmatic environments. Combination of these characteristics with the temporal information (residence time in different environments and timing of magma transfer between these environments) allows a dynamic picture of the plumbing system beneath Mt. Etna to be constructed.

Cooling and Crystallization of Trachytic Enclaves in Pantelleritic Magmas (Pantelleria, Italy): Inferences on Pantellerite Petrogenesis

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This study focuses on the study of trachytic enclaves hosted in pantelleritic lava and pumices emplaced during one of the most recent eruptive event at Pantelleria (~6-8 ka). Enclaves, from mm-sized fragments to dm-size blocks, have spheroidal to amoeboid shape and a typical globular surface. They are crystal-rich trachytes with ~30 vol% of large anorthoclase and less abundant mafic minerals. Vesicles ranging from few mm to 1-2 cm are distributed throughout the enclave and are thought to form as first boiling when the decompressing trachyte interacted with a pantellerite magma. These vesicles are commonly filled with microlite-free, vesicular glass. The groundmass presents spectacular textures that include fine to coarse spherulites to hopper and skeletal microlites (mostly anorthoclase) and 10-15 vol% of small vesicles (< 50 to 200 micrometers) with a rounded to elongated and polygonal shape and diktytaxitic voids. The residual glass, including vesicular glass in the large vesicles, has a pantelleritic composition (molar $Na_2O+K_2O/Al_2O_3 > 2$). We suggested that these groundmass textures were acquired during the mixing between trachyte and pantellerite magmas, due to rapid crystallization under a high degree of undercooling (DT= 100-150 °C). Vapour exsolution imposed by extensive crystallization (second boiling) produced the micro-vesicularity of the groundmass. Finally, vapour pressure squeezed the residual pantelleritic liquid into the large vesicles and/or outside of the enclaves.

Following these interpretations, we conclude that trachytic enclaves can be used as a natural experiment to infer chemical and physical processes driving the evolution of silicic magmas at Pantelleria. Pantellerite melts can be obtained from trachyte after extensive crystallization, followed by gas-driven filter pressing and consequent melt segregation.

The Different Explosive Styles of Stromboli Volcano by Remote Controlled OP-FTIR (CERBERUS) Measurements

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In this paper we present the results and interpretation of gas composition data collected by a permanent OP-FTIR system (CERBERUS) installed at Stromboli summit. The instrument allows remote control observation and measurement of gas emissions from different points within volcano's crater terrace, using an integrated infrared camera / scanning mirror / FTIR system. Given that an OpenPath Fourier Transform InfraRed (FTIR) spectrometer allows the simultaneously measure all the major species contained in volcanic gas emissions, we could observe the different explosive styles fed by Stromboli volcano.

Stromboli volcano, in the Aeolian island arc, is known as the "Lighthouse of the Mediterranean" for its regular (~every 10–20 min) explosive activity, launching crystal-rich black scoriae to 100–200 m height constituting a rich and impressive spectacle for both volcanologists and tourists from every part of the world. This ordinary activity has been classified in two types in relation to the their content of ash ejected. Type 1 is dominated melt ballistic particles whereas Type 2 consists of an ash-rich plume. On 18 July we recorded both explosive styles at the SW crater of Stromboli finding quite similar CO_2/SO_2 ratio, although we observed a higher value of SO_2/HCl molar ratio for the Type 2. Moreover prior to both types of explosions the CO_2 amount showed similar trend, whereas a different pattern in SO_2 and in HCl gas content, was observed. In detail type 2 was preceded by decrease in SO_2 and HCl amounts with respect to type 1. The decreasing trend observed before the onset of style 2 and the higher SO_2/HCl ratio might be an indication of overpressure that might have induced the difference between the two types of explosions. In this context, the evidence of no change in the amount of CO_2 and in CO_2/SO_2 ratio suggested us that this overpressure occurred in very shallow depths within the volcano feeding system. If our observations will be confirmed by other explosive event data, we will be able featuring the different source conditions triggering the ordinary explosive activity at Stromboli.

Simulation of the Etna 2001 Flank Eruption with a Steady-State Numerical Model of Magma Ascent

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Volcanoes exhibit a wide range of eruption styles, from relatively slow effusive eruptions, generating lava flows and lava domes, to explosive eruptions, in which very large volumes of fragmented magma and volcanic gas are ejected high into the atmosphere. Magma ascent dynamics in a volcanic conduit play a key role in determining the eruptive style of a volcano. However, due to the lack of direct observations in the conduit itself, numerical models, constrained with observational data, provide invaluable tools for quantitative insights into the complex magma ascent processes.

We have developed a multiphase multicomponent gas-magma-solid mathematical model, consisting of a set of non-linear partial differential and constitutive equations. The governing equations used in this work are designed to model multiphase fluid with disequilibrium processes, represented through the formalism of thermodynamically compatible hyperbolic systems as a system of conservative partial differential equations with relaxation terms. The stiffness of the terms modeling pressure and velocity relaxation and crystallization and degassing processes require an implicit treatment and thus an accurate solution of the resulting nonlinear system. The model has been implemented in a flexible numerical framework which is ideal for the highly non-linear set of equations which govern the multiphase, multicomponent, non-ideal system deriving from a real volcanic conduit.

For this work we used a 1D steady-state version of the model, which uses a shooting method to derive a magma input rate such that the pressure at the top of the conduit is equivalent to atmospheric pressure. This numerical model has been used to reproduce the 2001 eruption at Etna. The 2001 flank eruption is one of the most studied eruptive episode at mount Etna. This eruption, started at 17 July and ended at 9 August, was active from seven fissures at different altitude, showing different eruptive styles: fire fountains, Strombolian activities and lava effusions. The maximum lava flow rate calculated during the event was $31 m^3/s$ [Coltelli et al., 2007], with a mean of 11 m^3/s. From a mineralogical point of view, two different lavas were erupted. The vent higher than 2600 m a.s.l. (hereafter Upper vents, UV) erupted plagioclase-rich magma with an high crystal content (30-39 vol%, [Corsaro et al., 2007]). Crystal composition of UV scoria is composed by plagioclase (16-23 vol%), clinopyroxene (10-19 vol%) and olivine (1-3 vol%). On the other hand, the vents located at 2550 and 2100 m a.s.l. (hereafter Lower vents, LV) produced a plagioclase-poor magma with a lower crystal content than UV magmas (15-23 vol%, [Corsaro et al., 2007]). In these scoria, the most abundant phase is clinopyroxene (8-14 vol%), followed by plagioclase (4-7 vol%) and by olivine (1-3 vol%). These mineralogical differences were interpreted with two different plumbing systems for UV and LV: a shallow "central-lateral" one feeding the activity of the UV and an "eccentric" deeper one for LV. In order to better reproduce the physical processes of this eruption, proper solubility models for water and carbon dioxide, derived from VolatileCALC, and two different crystallization models, derived respectively from alphaMELTS using UV and LV whole rock compositions, have been adopted. Comparing the results obtained using respectively UV and LV crystallization models, we find a quite similar solutions, that means that the differences in the scoria erupted from UV and LV are not caused by the different whole rock composition, but are instead controlled primarily by magma ascent rate.

To investigate this aspect, we perform a sensitivity study on the magma chamber temperature, on the conduit radius and on the crystallization rate parameter (which controls the time needed for all crystal phases to reach the equilibrium profiles at a given pressure, temperature and water content). Using the estimation for volume flow rate and for crystal content for both magmas we are able to constraint the conduit radius and the temperature of the magma chamber. Furthermore, our numerical results indicate that the differentiation in UV and LV scoria is related to the different time available for crystallization. Our data show that LV magma is erupted before that crystals reach an equilibrium profile, while for UV the equilibrium content is achieved. An explanation for this fact is the presence of a shallow sill below UV where magma can circulate and reach the equilibrium crystal content, while for LV activities, magma ascends vertically without having enough time to completely crystallize. These conclusions are in

accordance with the plumbing systems proposed by Corsaro et al. [2007] and Behncke and Neri [2003], and allow us to validate the numerical model and to show how this tool can be very useful for a better comprehension of volcanic systems.

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Geochemical Composition of Noble Gases in Volcanic Rocks of Vulcano Island (Aeolian Islands, Italy) and Comparison with Fumarolic Fluids

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In this work, the elemental and isotopic composition of noble gases (He, Ne, Ar) in olivine- and clinopyroxene-hosted fluid inclusion have been defined for products with different evolutionary degree erupted at the Vulcano Island (Italy). The isotopic features of the rocks were compared with the isotopic signals given by fumarolic fluids to establish which type of magma actually feeds the gas emissions at the island. The analyzed products have various degree of evolution, namely: i) basalt and andesite belonging HKCA-SHO series (49-19 ka); ii) shoshonite and latite belonging SHO-KS series (1.9-1.5 ka). By doing this, the isotopic characteristics for the main magma compositions feeding the volcanism of the island have been determined.

The study of noble gases hosted in fluid inclusions was performed by single-step crushing technique for crystals of olivine and clinopyroxene from each sample. The isotopic concentrations of He, Ne and Ar were determined by mass spectrometry after standard purification methods in ultra-high-vacuum (UHV) lines. Fumarolic gases display a $^{3}He/^{4}He$ isotopic ratio within the range 4.8-6.2 R/Ra, showing large fluctuations through time. The lowest values (R/Ra < 5.2) are typical of fumarolic gases having very low contents of CO_2, He and N_2, and generally low emission temperatures; these have been related to the contribution of fluids from a hydrothermal system residing beneath La Fossa. Previous geochemical studies [Paonita et al., 2013] have constrained the typical magmatic end-member feeding fumaroles in the range of 5.2 to 6.2 R/Ra. This large range in the fumarolic gases probably results from mixing between fluids attributed to at least two ponding levels of latite magmas stored at depth around 3-3.5 km [Paonita et al., 2013]. The analyzed rocks show low isotopic ratios for $^{40}Ar/^{36}Ar$ (< 342) and $^{4}He/^{20}Ne$ (< 119.3), which is evidence for significant air contamination. The $^{3}He/^{4}He$ ratios vary between 3.30 and 4.66 R/Ra, being well below the theoretical R/Ra ratio of the deep magmatic source of Vulcano (see above). The decrease of He isotopic ratio in erupted products with respect to that of the emitted fluids could be attributed to crustal assimilation processes of the Calabrian basement with amounts variable from 10% to 25%. In this regard, the R/Ra ratio is well correlated with the Sr isotopic composition of the whole-rock and their evolutionary degree, except for the andesite that shows the highest isotopic values. Effects of crustal assimilation are also evident for 40Ar isotopes, which increase in more contaminated lavas. On the basis of the He/Ar* ratio (being Ar* the radiogenic Ar achieved by removing from the total Ar content the atmospheric-related Ar fraction), two mains groups of samples can be distinguished: i) basalt and andesite with high He/Ar* values (2.21-3.46) (these rocks evolved in deepest magmatic reservoir and are less contaminated); ii) shoshonite and latite having He/Ar* < 1 (these samples evolved in shallow magma chambers and show higher degree of contamination).

Main conclusion of this work is that the R/Ra values of the magmatic fluids presently feeding the fumarolic fields are higher than He isotopic ratio of the analyzed rocks. This suggest that new magma input have interested the plumbing system beneath Vulcano, at least after the most recent eruption studied here (Palizzi, 1.5 ky). The new magma did not have enough time to achieve any signature of aging and, above all, contamination by crustal material and/or fluids, since both processes should require considerable residence in a crustal chamber. A general working-model for the Vulcano volcanic system could therefore consist of two main steps: i) eruption of magma stored in crustal reservoirs, and ii) consequent magmatic recharge triggered by the eruptive event. In such a way, erupted products can acquire variable degree of contamination on the basis of the residence time and evolutionary degree, while the fumarolic gases can be fed by a different magma, fresher than the last erupted.

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Early Sub-Aerial Volcanism at the Island of Salina (Aeolian Archipelago)

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The early sub-aerial stage of activity at Salina island (Aeolian arc) has been studied by means of a volcanological field survey coupled with whole rock and in situ chemical analyses of volcanic rocks. This has offered the opportunity to reconstruct the magmatic processes that concern the storage dynamics at various levels of the plumbing system and styles of magma ascent toward the surface at Rivi and Capo volcanoes.

The geological field survey proved that Rivi and Capo volcanoes had contemporaneous activity and they constitute a N50°E directed volcanic complex, here named Rivi-Capo Volcanic Complex (RCVC). Capo volcano is constituted by a sequence of lava flows and pyroclastic deposits intensely intersected by dykes and sills, especially in its lowermost portion. Three main Formations have been identified: Lower Capo, Middle Capo and Upper Capo Formations. The succession of Rivi volcano is constituted by a ~250-m-thick alternating lava flows and subordinate scoriaceous fallout pyroclastic deposits, here divided in Lower Rivi Formation and Upper Rivi Formation.

Rock sampling has been stratigraphically constrained and leads to the reconstruction of feeding system processes through time. Samples have been analyzed to obtain major element concentrations of the whole rock together with in situ chemical analyses along core-to-rim profiles of plagioclase and clinopyroxene crystals. Whole rock compositions exhibit a general trend of evolution toward more basic terms within the three Formations constituting the Capo volcano and within the Rivi center. MELTS simulations and mass balance modeling suggest that the RCVC rocks are the result of fractional crystallization of plagioclase, clinopyroxene and olivine (ca. 45 vol.% of solid removed) from a primary magma. In addition to fractional crystallization, continuous recharge and mixing by more basic magma coming from the deep portions of the magmatic plumbing system contribute to the final volcanic rock composition.

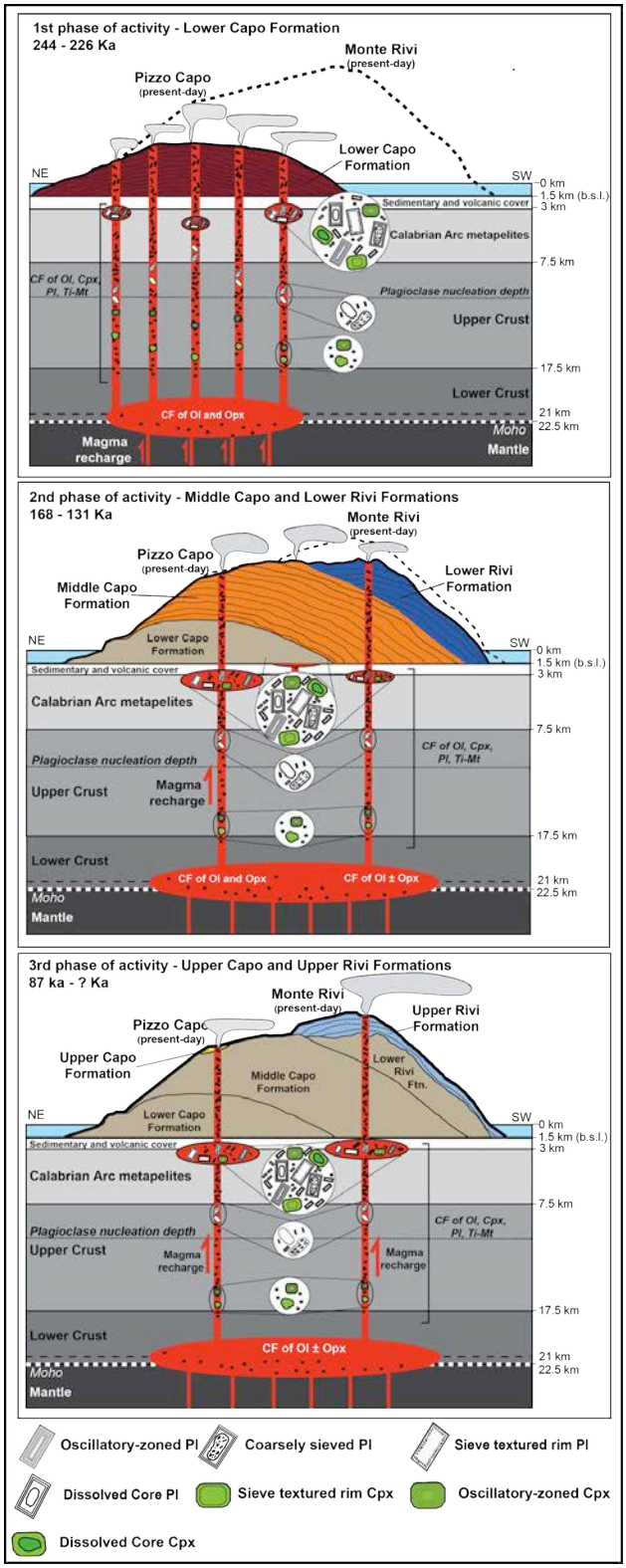

Figure 1. Sketch of the evolution of magma feeding system for the Rivi-Capo volcanic complex (taken from [Nicotra et al., 2014]).

Textural and in situ compositional data obtained on plagioclase and clinopyroxene crystals imply the presence of two main levels of storage and degassing characterized by quite distinct crystallization dynamics. Textural relationships among the crystal cores also indicate that magmas could have experienced variable decompression rates during their ascent toward shallow levels of the plumbing system. Here, residing magmas were affected by frequent episodes of recharge and mixing by more basic liquids as indicated by crystal disequilibrium textures at the rim (i.e., sieve textures). MELTS simulations confirm these differentiation dynamics, with most of products that are the result of fractional crystallization at ~21 km, ~3 km and during ascent between these two magma reservoirs. Superimposed to fractional crystallization, recharge and mixing by more basic magma occur at shallow levels of the plumbing system (~3 km). Magma recharge and mixing are more evident in the intermediate and final evolutionary phases of the RCVC, causing changes toward basaltic compositions.

All the available data emphasize that storage and transfer dynamics at the Rivi and Capo volcanoes are characterized by extended periods of contemporaneous activity during the emplacement of the Middle Capo and Lower Rivi Formations, which was fed by a common deep reservoir, elongated along a NE-SW direction (Figure 1). Furthermore, storage and transfer mechanisms changed throughout the considered timespan: a) first phase of the RCVC activity (244-226 ka), characterized N50°E directed fissural activity at the Capo volcano (Lower Capo Formation); b) second phase of the RCVC activity (Middle Capo and Lower Rivi Formations; 168-131 ka), with formation of the NE-SW morphological ridge of Mt. Rivi-Pizzo Capo, the progressive migration of the volcanic activity toward SW and progressive centralization of activity at Capo volcano; c) third phase of activity (Upper Capo and Upper Rivi Formations; 87 ka for Capo, not known for Rivi), with centralization of Rivi and Capo volcanoes due to formation of shallow magma storage levels at ~3 km. The integrated study proposed here suggests that the volcanological evolution of the RCVC was intensely controlled at a regional scale by the NE-SW tectonic alignment, which is one of the three major regional alignments present on the island and, more in general, in the Aeolian archipelago.

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Decadal Timescales of Magma Mixing at the Establishment of the Steady-State Activity at Stromboli

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The present-day activity of Stromboli is characterized by strombolian explosions ejecting black scoriaceous lapilli and ash. This persistent activity is interrupted by effusive eruptions and more energetic explosions (paroxsyms) emitting black scoriaceous bombs, lapilli, and gold pumices. The entire system is in a persistent steady-state of activity whose driving forces are still not completely understood. Investigating the evolution of the plumbing system toward the present-day condition is thus crucial to better constrain and understand the onset and development of the present-day activity.

We studied in detail two selected samples representative of the transitional eruptive phase from the pre-Sciara period to the present-day: (i) an older spatter lava sample from the pyroclasic succession of Chiappe Lisce (Post-Pizzo activity) emplaced prior the beginning of the present-day activity; (ii) a black scoria spatter covering the youngest collapse scarp, probably ejected during one of the early paroxysms of the present-day activity. Both samples have similar paragenesis with phenocrysts of olivine, clinopyroxene and plagioclase. We recognize several different types of clinopyroxene textures with different recurrence among the two samples. In detail, multiple banded clinopyroxene with evident resorption features, characterizes the older Chiappe Lisce shoshonite sample, recording several pulsatory intrusions of new mafic magmas into the system and pointing to the establishment of the steady-state condition. Contrarily, single diffused band and/or patchy cores are found in the basaltic scoriae of the present-day paroxysm. We applied the diffusion chronometry to suitable clinopyroxene crystal bands to temporally constrain the occurrences of these refilling events. Decadal timescales characterise the shallow magma reservoir from the post-Pizzo period onward pointing to a progressive transition toward the present-day condition.

The Onset of an Eruption: Selective Assimilation of Hydrothermal Minerals during the Opening Phase of the 2010 Summit Eruption of Eyjafjallajökull Volcano, Iceland

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The 2010 summit eruption of Eyjafjallajökull volcano (Iceland) started on 14 April and continued for 39 days. The whole duration of the activity can be divided into different phases, characterized by variable intensity and eruption dynamics. The opening stage of the eruption, in particular, lasted few hours, during which the magma intruded into the glacier, melting the ice to the surface. In this subglacial stage the activity was dominated by the emission of ash-poor, vapour-rich clouds, with the sedimentation of a very thin ash layer in the very proximal area. The intensity of the summit eruption gradually increased during the day, and culminated with the emergence of a 9-10 km high, dark ash-laden plume, which continued, with variable intensity, until 18 April.

We focus here on the opening stage of the event (first 3-4 hours), which represents a unique opportunity to investigate the immediately pre-eruptive dynamics.

Tephra samples of the whole explosive activity were collected from the pristine fallout deposits ~4.5 km east from the crater. On the whole, the juvenile components along the eruptive sequence show a large morphological and textural variability. The peculiarity of the products of the opening phase is the presence of abundant (~40 vol.%) blocky, dense, obsidian-like, microlite-poor clasts. These features suggest important quenching effects of the first body intruded at the base of the ice cover, after eruptive fracture opened at earth-ice interface.

The groundmass glasses of the opening stage ash clasts show major and trace element contents with a larger compositional variability than those of the products from the following phases. Some clasts, in particular, are characterised by higher SiO_2, Al_2O_3 and Na_2O abundances, with more scattered trace elements. In order to check possible micro-scale isotopic variability, in-situ $^{87}Sr/^{86}Sr$ values were analyzed on matrix glasses of single ash clasts, choosing glasses with different textures and compositions, as well as on plagioclase crystals. Similarly to elemental variations, $^{87}Sr/^{86}Sr$ ratios reveal the presence of groundmass glass with large isotopic variability, ranging from the typical values recorded in Icelandic magma (< 0.70380), up to much higher values ($^{87}Sr/^{86}Sr$ = 0.70668), never found in Icelandic volcanics. The groundmass glasses having higher Sr isotopes also show anomalous major and trace element abundances. Conversely, plagioclase crystals from the same stage of activity have low $^{87}Sr/^{86}Sr$ values, similar to those of the whole rocks and glassy groundmasses from the following eruptive phases.

These data suggest that the very first erupted magma selectively assimilated a high amount (20-55 wt%) of alteration minerals possibly formed in veins or vacuoles by seawater-derived hydrothermal fluids. Among the variety of hydrothermal minerals, the association of zeolites + silica minerals (chalcedony and quartz) could be the most likely assimilated component, leading to increase SiO_2, Al_2O_3, K_2O and Na_2O contents and decrease MgO in the silicate melts. The assimilated zeolites possibly contained particularly high Rb, Ba, U, and low Sr and Pb contents. Melting started at lower T in these veins when zeolites lost most of their constitutional water and it was probably a rapid process. We suggest that magma firstly moved up cutting its way through hydrothermally altered rocks, possibly through a process of stress corrosion which weakened the host rocks and partially dissolved hydrothermal minerals. The main dyke body provided the necessary heat for the selective assimilation of the host rocks, mainly changing the chemical and isotopic composition of the melt (but not of the already formed phenocrysts).

The results also confirm the importance of studying the products of the opening phases of explosive eruptions to shed light onto the immediately pre-eruptive conditions.

Petrophysical Properties of the Sub-Hyblean Lithosphere: insight from Deep-Seated Xenoliths

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As it is known, deep-seated xenoliths provide us direct information about the inaccessible portions of the lithosphere. The present work focuses on a suite of xenoliths collected within Miocene tuff-breccias at Valle Guffari (Hyblean Plateau, south-eastern Sicily). They mainly consist of: a) ultramafics, consisting of spinel facies peridotites and pyroxenites (some garnet bearing) with rare phlogopite occurrence; and b) feldspar-bearing suite, represented by metabasites and anorthosites.

The size of collected specimens ranges from about 2 to 30cm (most abundant 6-8cm); the shape is rounded and most of them are relatively fresh and suitable for our investigation.

Spinel facies peridotites (harzburgite and lherzolite) mostly show protogranular texture, with kink-banded olivine and orthopyroxene, with smaller clinopyroxene and spinel. Infrequent porphyroclastic texture, and very rare equigranular mosaic texture also occur. Finally, intergranular glass and veinlets of metasomatic glass are ubiquitous.

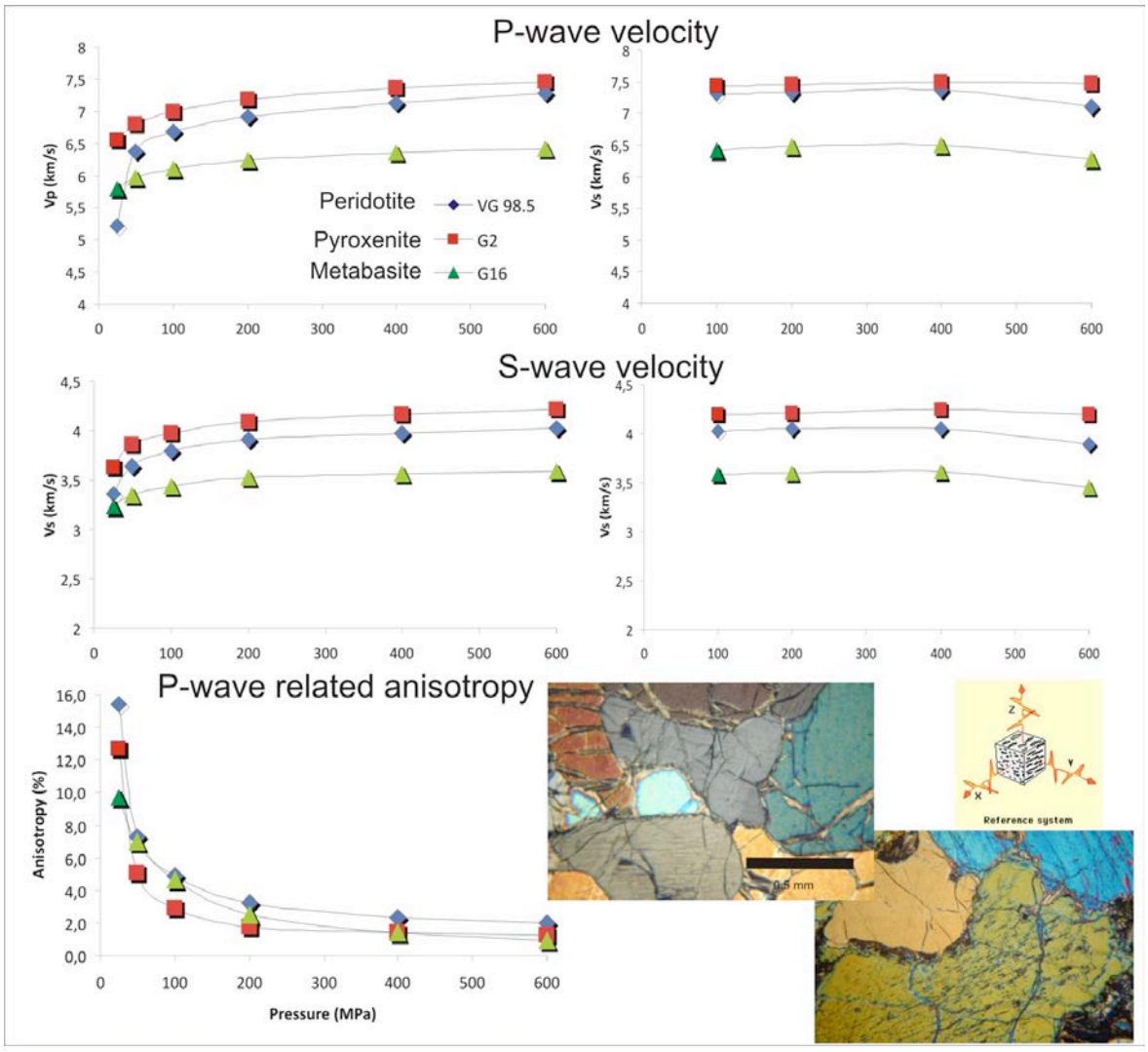

Figure 1. Vp, Vs and Vp-related seismic anisotropy of the investigated Hyblean xenoliths, together with photomicrographs of common protogranular texture.

Spinel-bearing pyroxenites consist of Cr-diopside websterites, Al-augite websterites, spinel and garnet clinopyroxenites, with ubiquitous intergranular glass. Cr-diopside websterites, which often occur as veins within peridotite, exhibit xenoblastic granular or polygonal texture; garnet may be also present. Al-diopside websterites exhibit polygonal texture, with exoluted pyroxene. Al-augite pyroxenite, which are the ultracoarse specimens (>20mm) are not very abundant; they exhibit igneous cumulitic texture with pyroxene megacrysts and neo-blastic sub grains.

Finally, feldspar bearing metagabbroes and anorthosite xenoliths are considered to represent the inaccessible sub-Hyblean crustal portion [Scribano et al., 2006].

Previous studies [Atzori et al., 1999] highlighted as equilibration conditions of pyroxenites are about 0.98GPa at 740°C (spinel pyroxenite) and 1.32 GPa at 1040°C (garnet pyroxenite). Unfortunately, no reliable PT values could be obtained for metabasites because of evident disequilibration features; nevertheless, Nimis and Ulmer [1998] estimates provided P values of 0.5 GPa for clinopyroxene within metagabbros.

The seismic properties of selected deep-seated xenoliths (spinel harzburgite, pyroxenite and metabasite; Punturo et al., 2000] considered to be representative of the sub-Hyblean main lithologies, were experimentally determined with a multi-anvil apparatus at confining pressure up to 600MPa (room temperature) and up to 600°C (at 600MPa; Fig.1). Laboratory measurements of 3D distribution of Vp and Vs permitted the intrinsic P-wave related seismic anisotropy and shear wave splitting to be also determined, together with density changes as a function of pressure and temperature. Finally, in order to understand the contribution of Crystallographic Preferred Orientation of olivine and pyroxenes to seismic anisotropy of deep lithosphere, we also carried out measurements on thin sections with a microscope equipped with Universal Stage.

Results provide direct petrographic, compositional and petrophysical data which may contribute to define the nature of the sub-Hyblean lithosphere and permit available geophysical data to be constrained and interpreted at a better extent.

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Experimental Constraints on Pre-Eruptive Conditions of Trachytic Magmas at Pantelleria Island

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Pantelleria Island (Italy) is the type locality of pantelleritic rocks, an iron- and alkali-rich peralkaline rhyolite. Pantelleria is also well known in the petrological literature for the typical bimodal suite of its eruptive products, a mafic end-member (mildly alkaline, or transitional basalt) and a felsic end- member, which consists of metaluminous, or slightly peralkaline trachytes and pantellerites.

Two alternative models have been proposed for the origin of the felsic end-member at Pantelleria Island: protracted fractional crystallization of alkali basalt and partial melting of alkali gabbro cumulates. In detail, although it is generally accepted that pantellerite may derive from trachyte via fractional crystallization at low pressure and an oxygen fugacity of around 1,5 units below the NNO (nickel nickel oxide) solid buffer [Di Carlo et al., 2010, Scaillet et al., 2006], the origin of trachyte is still highly debated. In this context, our study is aimed at experimentally constraining the pre-eruptive conditions and evolution of the trachytic melts.

We present experimental phase equilibria carried out on a trachyte bulk-rock compositions with a peralkaline index [PI=molar $(Na_2O+K_2O)/Al_2O_3$] = 0,97] representative of the post-caldera volcanism at Pantelleria island. All the experiment were performed with an internally heated pressure vessel (IHPV) within the temperature range 950°C – 850°C, for pressure between 100 – 150 MPa, with oxygen fugacity below the NNO and H_2O dissolved in the melt between nominally anhydrous and up to 5 wt%. Experimental products were first characterized by scanning electron microscope (SEM) and then analysed by electron microprobe (EMP).

At 950°C and water saturated conditions charges were above liquidus, in the water-undersaturated charges pyroxene is the liquidus phase followed by olivine and alkali feldspar. In the most crystallized charges (lower temperature and water content) generally the most abundant phase is the alkali feldspar followed by clinopyroxene and olivine. Comparison of the experiments with natural phase abundances and compositions will allow us to constrain the crystallization conditions (pressure, temperature, H_2O content, and redox state) of the trachytic magma, whose phase assemblage is characterized by alkali feldspar (An_{03-09} Ab_{67-72} Or_{23-27}) clinopyroxene (Wo_{41-44} En_{26-34} Fs_{25-32}) and olivine (Fo_{20-28}), as well as the liquid line of descent of the trachytic melts toward a most evolved rhyolitic compositions.

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A Melt Inclusion Study of Mafic to Felsic Tephra at Ustica Island, Southern Tyrrhenian Sea

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Ustica is a Quaternary volcanic island located in the southern Tyrrhenian Sea. The island is the relit of a large volcanic edifice and its base lies 2000 m below the sea level. During its lifetime (750-100 ka BP) erupted mostly mafic magmas and subordinated trachytic magmas. Among the explosive eruptions, basaltic pyroclastic surge deposits are recurrent throughout the volcanological history of Ustica, such as a widespread deposit in the central part of the island and the Falconiera tuff-cone in the northwest sector of Ustica. A trachytic pumice fallout was produced only during the most energetic event (sub-plinian at most) forming an important marker bed in the island. These eruptive units are poorly known from the petrological viewpoint and data on volatiles in melts inclusions are lacking. With the aim to fill this gap we carried out a study of melt inclusions (MIs) hosted in olivine, feldspar and amphibole phenocrysts, in order to determine H_2O and CO_2 concentrations by FT-IR spectroscopy as well as Cl, F, S by electron microprobe. Selected samples are basaltic and trachytic in bulk rock composition. In the basaltic products olivine host compositions range from Fo_{88-74} while in the trachytic products olivine and feldspar host compositions range from Fo_{60-48} and An_{60-30}. Major element compositions of MIs range from 46 to 63 wt.% SiO_2 and Na_2O+K_2O range from 4 to 10 wt.%. Water concentrations in melt inclusions are variable between 0.5 and 3 wt.% while CO_2 concentration is usually below the detection limit (50 ppm) of the FT-IR spectrometer. The results of this study allow deriving the melt inclusions entrapment conditions as well as the pre-eruptive storage conditions of the magma that fed the most energetic eruptions in the island, and also better constrain the plumbing system of Ustica volcanic complex.

SO_2 flux at Mount Etna between 2005 and the 2011: Results and Perspectives

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Mount Etna, is one of the most active volcanoes in the world, and is also regarded as one of the strongest volcanic sources of sulphur dioxide (SO_2) emissions to the atmosphere, accounting for ~15% of the global flux of volcanic S into the Earth's atmosphere. Regular SO_2 flux observations from both summit and flanks have been performed at Mount Etna since 1987 using COSPEC and since late 2004 by the FLAME scanning spectrometer network. In the period between 2005 and 2011 Etna has displayed an intense eruptive activity, which spanned from soundless lava flows to vigorous lava fountains. We present here bulk SO_2 flux observations carried out in this time window. Over the seven years noteworthy changes in gas flux have been observed strongly correlated with the eruptive activity at both short and long-time scale. SO_2 flux has varied between 200 and 21,000 Mg/day (standard deviation of 1900 Mg/day). Results highlights stages of progressive magma degassing and increase trends reflecting the ascent of volatile-rich magma within the volcano shallow feeding system. Detailed analysis throughout the seven year revealed waxing-waning steps suggesting cycles of volatile rich magma supply from the depth to the shallow part of the feeder conduit. Considering the original content in sulphur of Etna's magma, the balance between the erupted magma and the SO_2-degassed magma budget, which sustained the observed bulk plume emission, has been explored. Short- and long-time scale estimates of degassed magma enabled us discriminating between steady-state magma degassing-erupted transfer processes and unbalances due to excess degassing.

Influence of Tectonics on Storage and Transfer Mechanisms of Basaltic Magmas Emitted in the North-Western sector of Pantelleria

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Most of the erupted products on the Island of Pantelleria exhibits marked evolutionary degrees and high alkali contents. Their emplacement is the result of violent explosive eruptions, which were occasionally accompanied by caldera-forming events. Throughout the eruptive record, however, low-to-mid Strombolian eruptions and lava flow emission of less evolved products has been also recognized. The basaltic manifestations are subordinated to the evolved volcanic rocks and concentrated essentially in the north-western sector of the island. Our study focuses the attention on these basaltic products, which have been investigated integrating structural and petrological methodological approaches (textures and in situ microanalyses coupled with whole rock geochemistry).

The structural analysis of the eruptive fissures and scoria cone alignments put into evidence their orientation along the main NW-SE regional trends even for events that took place in distinct times. This suggests that the emplacement of basaltic magmas is primarily controlled by regional tectonics.

The detailed petrological study of the basaltic products provides evidence for different suites among the spectrum of the less evolved compositions. Major elements suggest that primary magmas underwent differentiation processes chiefly ruled by fractional crystallization under different chemical and physical conditions. Trace elements for the whole rock indicate the existence of a source with rather common characteristics, being ratios of petrologically significant incompatible elements similar for basalts belonging to different suites.

The role of differentiation processes has been also evaluated through the textural and compositional analyses performed on selected olivine, clinopyroxene and plagioclase crystals, being these minerals rather sensitive to changes of the thermodynamic equilibrium. The chemical analysis of minerals has taken into consideration key parameters such as the forsterite content in olivine, the Mg# in clinopyroxene, the anorthite and iron contents in plagioclase, and their variation along core-to-rim profiles in order to detect chemical and/or physical variations during the crystal growth. This approach allowed the identification of three main suites of basalts (s.l.), namely products with: 1) abundant euhedral and highly forsteritic olivine, subordinate clinopyroxene with high Mg# and plagioclase almost exclusive of groundmass; 2) anhedral olivine, clinopyroxene and plagioclase (more abundant) with Fo, Mg# and An lower than basalts of the first group; 3) abundant plagioclase, subordinate clinopyroxene and olivine as micro-phenocrysts in the groundmass.

The co-presence in a rather limited area of the north-western sector of the island of basalts (s.l.) with distinct assemblages and mineral textures is plenty evidence for variable chemical-physical conditions during the storage and for different styles/rates of magma ascent upward to the surface. Integration of the obtained data has led us to infer a possible volcano-tectonic model of emplacement for basaltic products in the north-western sector of Pantelleria. Particularly, the observed textural and compositional characteristics of minerals highlight that styles and rates of magma transfer from the deep to the shallow levels of the plumbing system can be distinct even among the poorly evolved products. In this regard, regional tectonics has a prominent control also on the magma residence and therefore on the possibility to develop variably differentiated basalts via fractional crystallization.

En-Route Formation of highly Silica-Undersaturated Melts through Interaction between Ascending Basalt and Serpentinite-Related Saline Brines: Inference from Hyblean Cenozoic Nephelinites, Sicily

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Neogene to Quaternary volcanic rocks from the Hyblean area (south-eastern Sicily) mostly consist of basalts with both alkaline and tholeiite affinity, erupted in submarine settings in most cases. Minor basanites and nephelinites also occur. Nephelinites mark the resuming of eruptive activity in this area during Late Miocene, after a non-magmatic period of 50 Ma (i.e., the Eocene hiatus), either in form of diatremes or lava flows. Hence, nephelinite lavas were the final volcanic products on Early Pleistocene.

The Hyblean nephelinites show both aphyric (especially in diatremic facies) to strongly porphyritic textures with high color index. The porphyritic types consist of olivine, strongly zoned Ti-rich augite phenocrysts immersed in a groundmass of Ti-augite, nepheline, abundant apatite and Fe-Ti oxide micrograins. Sodalite-group micro-phenocrysts sometimes occur in the Hyblean nephelinites. Scarce amounts of interstitial glass also occur, displaying either a nepheline-like, hauyne-like or feldspar-like compositions. In the latter case, acicular plagioclases, a few micrometers in size, are immersed in the glass. The glassy groundmass is often enriched in S, Cl and P. This would imply high S and Cl fugacity in the eruptive system during late stages of its cooling history at variable fO_2 conditions, generally well above the QFM buffer as deduced by their mineral assemblages. In some cases, the melanocratic character of these volcanic rocks is strengthened by the occurrence of Mg-rich olivine and variously resorbed orthopyroxene xenocrysts, being fragments of mantle peridotites. Whole rock analyses of Hyblean nephelinites display conflicting geochemical aspects: on the one hand, some features conform to world wide nephelinites (e.g., SiO_2 content as low as about 38 wt.%; rather high contents of Ba, Sr, Th, Ta, Nb, LREE, Pb and P; Chondrite-normalised REE patterns being roughly linear hence displaying a strong REE fractionation). On the other hand, Hyblean nephelinites share some geochemical characteristics with the coexisting basalts (e.g., the Sr-Nd isotopic compositions indicate a time-integrated depleted source; some geochemical proxies widely used for fingerprinting magma type closely fit those of Ocean Island Basalts; K_2O, TiO_2, Zr, Hf, Y contents are similar to those of coexisting alkaline basalts). In addition, important variations are present among the published nephelinite analyses with respect to some major and trace elements (e.g., Na_2O content varies from about 2 wt.% to about 4 wt.%; MgO from about 11 wt.% to about 16 wt.%; CaO from 11 wt.% to 15 wt.%). More interestingly, detailed field sampling indicates strong chemical variations even within a distinct lava flow [unpublished data of the Authors].

The origin of Hyblean nephelinites has been previously related to the influence of metasomatic agents (i.e., carbonatite fluid) in the mantle source. Conversely, we put forward the hypothesis, plenty conforming the above mentioned data, that these nephelinites originated from an ascending basaltic magmas that assimilated different amounts of deep-seated evaporite-like salts (Ca-Mg sulfates, halite, carbonates, minor phosphates), providing an adequate magma: salt volume ratio. In this respect, it is opportune to recall that recent works suggest the serpentinite nature of a large part of the unexposed section of the Hyblean lithospheric section. Since the serpentinization process requires pure H_2O, the involved seawater-derived serpentinizing fluid will undergo total out-salting. In particular, about 10.5 kg of salts can be deposited per m3 of serpentinized peridotite. Salts are likely accumulating in pores, fractures and major tectonic discontinuities of the serpentinite wall rocks, giving rise to the accumulation of huge salt deposits through time. In addition, hot aqueous fluids, due to the local dehydration of the serpentinite at the contact with the ascending basaltic magma, can form highly mobile saline brines. The latter, in their supercritical state, let the salt assimilation by slightly superheated basalt magma a thermodynamically viable process. In case of fluid oversaturated magmatic systems, diatreme eruptions have occurred; otherwise, lava flows have been emplaced.

Characteristics of the enriched Source of Mildly Alkaline Basalts Erupted at the Eyjafjallajökull Volcano, Iceland

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The 2010 flank eruption of the Eyjafjallajökull volcano (Iceland) offers a great opportunity to investigate the magma source characteristics in an area where spreading plate boundary-derived and mantle plume-derived magmatism interact, affecting considerably the geochemical signature of volcanic rocks. Early phases of the eruption at the Fimmvörðuháls Pass were characterized by the emission of primitive basaltic lavas with mildly alkaline affinity. Volcanic rocks contain a mineral assemblage constituted primarily by olivine (Fo_{70-88}) and plagioclase (An_{57-83}) in rather similar proportions. In this paper, the suite of primitive basalts has been used to get information on the mantle source features and to understand main factors controlling genesis of icelandic alkaline and transitional basalts, which preserve an unusual enriched signature with respect to other ocean ridge basalts of the Mid Atlantic Ridge.

Major element variations suggest limited evolutionary degree of the 2010 Eyjafjallajökull magmas, highlighting the minor role played by differentiation processes such as fractional crystallization. The observed rather constant trace element ratios also reveal the occurrence of a quite homogeneous magma source. In order to constrain the compositional features of magmas at the mantle source, the 2010 Eyjafjallajökull geochemical dataset has been considered in combination with whole rock compositions of Katla basaltic products, as these two volcanic systems are thought to be geologically related at depth. Starting from whole rock major and trace elements, compositions of these magmas have been re-equilibrated at mantle conditions by adding variable proportions of a mafic mineral assemblage, constituted by olivine (Fo_{87}) and clinopyroxene (Mg# 80), until the crystallizing olivine within the magma is equilibrated to that in the mantle with Fo_{88}. The concentration of highly incompatible elements for these mantle-equilibrated magmas has been assumed as index of the partial melting degree (F), so that high and low concentrations of elements characterized by distribution coefficients (D) <0.001 reflect low (FL) and high (FH) degrees of melting, respectively. Based on this, an enrichment ratio (Ei) for each trace element has been calculated through linear regression on Harker diagrams, using the concentration of Th as index at FL and FH.

The pattern of resulting enrichment ratios displays negative anomalies for LILEs (Rb, Ba, K, Sr) more marked than those of patterns obtained by melting of a classical spinel- or garnet-peridotitic source. This implies that unusual mantle mineral phases, retaining preferentially these elements, are present in the source region of Eyjafjallajökull and Katla magmas. In this regard, the pattern of enrichment ratios obtained for Eyjafjallajökull-Katla magmas well matches that obtained from fractional melting of a peridotite bearing hydrous phases (amphibole/phlogopite). This put forward the idea that Eyjafjallajökull magmas are generated through partial melting of enriched mantle domains where hydrous minerals have been stabilized as a consequence of metasomatic processes. Our inferences agree well with the enriched signature of these products for what concerns either the mildly alkaline affinity or the value of incompatible trace element ratios, which have rather unusual characters with respect to the depleted signature of other typical mid-ocean ridge products.

Petrology and Geochemistry of Basalts of Monogenic Cones in the northern main Ethiopian Rift (Ethiopia)

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The Main Ethiopian Rift (MER) is a key sector of the East African Rift System, extending along NE-SW to N-S directions for about 1000 km, from the Afar depression at north to the Turkana depression at south. The MER is characterized by high rates of crustal extension coupled with high volumes of intruded and erupted magmas. Geochemistry of erupted products is characterized by dominant felsic compositions and subordinate mildly alkaline basalts. These two end-members are often associated with a bimodal distribution in the same volcanic system. Such variable geochemical compositions strongly influence eruptive mechanisms of each system and, consequently, the morphology of volcanic edifices. The northern MER is characterized by rhyolitic central volcanoes (Fantale, Kone, Boseti, Gedemsa), fissural basaltic lava flows from fissural eruptions and basaltic monogenic scoria cones. Central rhyolitic volcanoes and fissural basalts occur along en-echelon tectonic segments, located within the central portion of each branch of the rift and joined by transitional areas, in which monogenetic basaltic scoria cones with the most primitive compositions outcrop. The aim of this study is to investigate the origin of these basaltic monogenic scoria cones, and to have insights on their relationships with the fissural basalts erupted along the rift. About 40 lava and scoria samples have been taken from the aligned scoria cones between Fantale volcano, at north, and Gedemsa caldera at south, along a segment of rift about 80 km long. Petrographic observations of collected samples, together with micro-analytical studies of core-to-rim compositional profiles of plagioclase phenocrysts have been performed, in order to reconstruct crystallization dynamics and magmatic differentiation processes. Furthermore, major and trace elements for the whole rock have been modeled by means of MELTS software, in order to have insights on the features of the magma sources and the processes affecting the magmas during their ascent towards the surface.

Whole rock major and trace elements compositions show a certain degree of geochemical variability both in the same scoria cone and among the different cones. More in detail, trace elements compositions show high variability of some compatible elements such as Ni, Cr and, to a lesser extent, Sr, suggesting fractionation of mafic mineral phases such as olivine and pyroxene. However, the homogeneous concentrations of REEs and other incompatible elements, together with the absence of negative Eu anomalies suggest that more complex mechanisms are responsible for the observed variability. For example, MELTS simulations (P = 100 MPa; T = 1000-1500°C; fO_2 = QFM, QFM+1, QFM-1, absent; H_2O = 1) suggest the presence of two different parent magmas with very different contents of Sr, Zr and Nb and other incompatible elements. The occurrence of the two parent magmas is not related to the spatial distribution of the scoria cones along the rift, since samples of the same rift segment show different compositions, and, in some cases, similar magmas were erupted in correspondence of cones several km far.

The occurrence of plagioclase textures with oscillatory zoning of An, not accompanied by variations in the FeO content, leads to exclude the hypothesis that the observed variations are the result of a continuous recharge of the magma chamber and rather suggest that the main processes acting in the shallow reservoir are related to cumulus of crystals (i.e., mainly plagioclase, clinopyroxene and olivine) at its bottom and magma convection. This leads to the idea of a poorly perturbed and open shallow magma reservoir, which is elongated along the rift direction. Single batches of magma rose up from this reservoir along weakness areas of the rift, producing the present-day basaltic monogenic scoria cones fields aligned along the rift main direction. Although magma ascent occurred along the same weakness zones parallel to the rift elongation through time, we provide evidence for significant chemical variations. These changes could be due to heterogeneity at the source inherited by the parent magma. Isotopic and radiometric data will be necessary, however, to test the reliability of this hypothesis.

Spinel Lherzolite plus Garnet Pyroxenite: Mantle Ingredients for Explaining the Geochemical Signature of Mt. Etna Alkaline Magmas and their Compositional Variations

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Attempts to explain the long- and short-term geochemical variability of volcanic rocks erupted at Mt. Etna have been done by several researchers during the last decades. This variability is characterized by increase of LILE such as Cs, Rb, K, $^{87}Sr/^{86}Sr$ and decrease of $^{143}Nd/^{144}Nd$, $^{206}Pb/^{204}Pb$, $^{176}Hf/^{177}Hf$ for products emitted after the 1971 eruption. These features have not been ascribed exclusively to differentiation processes acting at crustal levels (fractional crystallization, crustal assimilation, volatile-induced differentiation) but also to the prominent role of compositional heterogeneity at the source. In this regard, notable findings have been achieved from investigations on the source of Mt. Etna magmas, which are summarized as follows: 1) mixed depleted-enriched signature; 2) evidence of modal metasomatism (phlogopite and amphibole), more marked in recent products; 3) fractionation of HREE and $^{176}Hf/^{177}Hf$ signature that imply together the presence of residual garnet preferentially retaining HREE and affecting the Lu/Hf ratio; 4) temporal decoupling between proportions of the residual garnet and metasomatic phases involved in partial melting, which could be indication of at least two lithologies (one garnet-bearing, the other amphibole/phlogopite-bearing) involved in partial melting.

Characteristics of the Etnean mantle source have been supposed similar to those of the Hyblean mantle, an assumption justified by the affinities of the Etnean and Hyblean alkaline magmas for what concerns REE and other trace element ratios and Sr-Nd-Pb-Hf isotope compositions. Based on these assumptions, we have modeled partial melting of a composite source constituted by two rock types, inferred by geochemical features and observation in some Hyblean xenoliths: a spinel lherzolite bearing hydrous phases (phlogopite and amphibole) and a garnet clinopyroxenite. We have thought the latter in the form of veins intruded into lherzolite, interpreted as metasomatic high-temperature fluids (silicate melts) crystallized at mantle conditions.

Partial melting modeling has been applied to each rock type and the resulting primary liquids, obtained through calculations, have been then mixed in various proportions. These compositions have been compared with Etnean alkaline melts re-equilibrated to mantle conditions. Our results are outstanding, as concentrations of major and trace elements along with the water obtained from the modeling are remarkably comparable with those of Etnean melts re-equilibrated at primary conditions. Different proportions of spinel lherzolite with variable modal contents of metasomatic phases and garnet pyroxenite can therefore account for the signature of a large spectrum of Etnean alkaline magmas and for their geochemical variability through time, emphasizing the crucial role played by compositional small-scale heterogeneity of the source. Magmas with variable compositions and volatile contents, inherited directly from the source, can then undergo distinct histories of ascent and evolution, leading to the wide range of eruptive styles observed at Mt. Etna volcano.

From a geodynamic standpoint, our model implies a source of Mt. Etna magmas rather shallow (<3 GPa), excluding the presence of deep mantle structures. Partial melting should occur consequently as a response of decompression due to extensional tectonics and shallow mantle upwelling within the framework of regional tectonics that affect the eastern Sicily, which are characterized by substantial compressive regimes.

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SESSION 4

Volcano Surveillance and Hazard

Atmospheric Water Vapour Tomography for Improving DInSAR Deformation Measurements on Mount Etna

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The satellite techniques are today frequently used in geodesy. Measures of the size and shape of the Earth play an important role, especially in the volcanic areas. One technique capable of such measures is the differential SAR interferometric (DInSAR) technique. The measurement of ground deformations with DInSAR technique is based on the comparison between two SAR images acquired at different times. If a ground deformation occurs between two satellite passes in the same area, the path differences between the sensor and the ground lead to a difference in the phase of the back-scattered radar wave. Among various perturbations affecting interferograms, atmospheric artifacts are one of the most significant and, probably, the most difficult to identify and reduce.

A particular synergy among GPS and SAR techniques, to improve the precision of the current ground deformation monitoring techniques, is here investigated. The study of atmospheric anomalies in the GPS EM waves propagation is useful to extrapolate information about the wet refractivity field. Because of its height and the quite variable weather conditions, the estimation of Mount Etna atmospheric anomalies using GPS measurements have noticeable importance to calibrate the SAR interferograms and to establish the "actual" ground deformation of the volcanic edifice. In this study we presented a method to obtain a 3D wet refractivity field tomography, starting from the GPS output data analysis of "Etn@net" framework.

The GPS processing has been carried out by using the GAMIT software and adopting appropriate processing parameters. A new software was developed for deriving the tropospheric tomography from the outcome of the GPS processing. The code was validated by using synthetic tests which assume different structures of the atmospheric anomalies and random noise in the worst case scenario. The results of the tests proved that the tomography software is able to reconstruct the simulated anomalies faithfully.

The code was applied to study the structure of the atmosphere in an actual case, by selecting the day of August 12th, 2011 at 10.00 am. The results of the tomography clearly indicate important features of the refractivity field of the studied day able to produce artifacts in the interferograms. In conclusion, this study prove that this new software is able to reveal the tropospheric anomalies and thus it is an useful tool to improve the results of the SAR interferometry.

Seismic Hazard and Related Risk at Mt. Etna Volcano: a Contribution to the Improvement of Emergency Plans

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Natural disasters, such as earthquakes and volcanic eruptions, have strong effects on the socio-economic well-being of countries and their people. The consequences of these events can lead to complex cascades of related incidents, and in more serious contexts they can threaten our basic survivability. The problem of the seismic risk is a well-known issue at Etna due to the high-intensities volcano-tectonic earthquakes that frequently damage the very populated flanks of the volcano.

In the framework of the european UPStrat-MAFA project, seismic hazard was performed following the probabilistic approach (PSHA) based on historical macroseismic data, by using the SASHA code [D'Amico and Albarello, 2008]. This approach uses intensity site observations to compute the seismic history for each investigated locality; the results, are expressed in terms of maximum intensity expected in a given exposure time, for exceedance probability thresholds.

The seismic site histories were reconstructed from the database of macroseismic observation related to the historical catalogue of Mt. Etna from 1832 to 2013 [CMTE, 2014], implemented by "spot" observations as far back as 1600 [Azzaro and Castelli, 2014]. To improve the completeness of the site seismic histories, the dataset of the observed intensities was integrated with 'virtual' values, calculated according to attenuation laws. The attenuation model applied is based on Bayesian statistics performed on the Etna dataset [Rotondi et al., 2013], and provides the probabilistic distribution of the intensity at a given site.

The hazard maps, calculated using a grid spaced 1 km, shows that for short exposure times (10 and 30 years, Figure 1a), volcano-tectonic earthquakes are the main source of shaking for the area. In particular localities in the eastern flank of the volcano have very high probabilities to suffer damage at least of VII degree in the next 30 years. Moreover, the de-aggregation analysis between magnitude vs seismic source demonstrates that S. Tecla fault (STF in Figure 1b) is one of the structures that mostly contribute to the hazard.

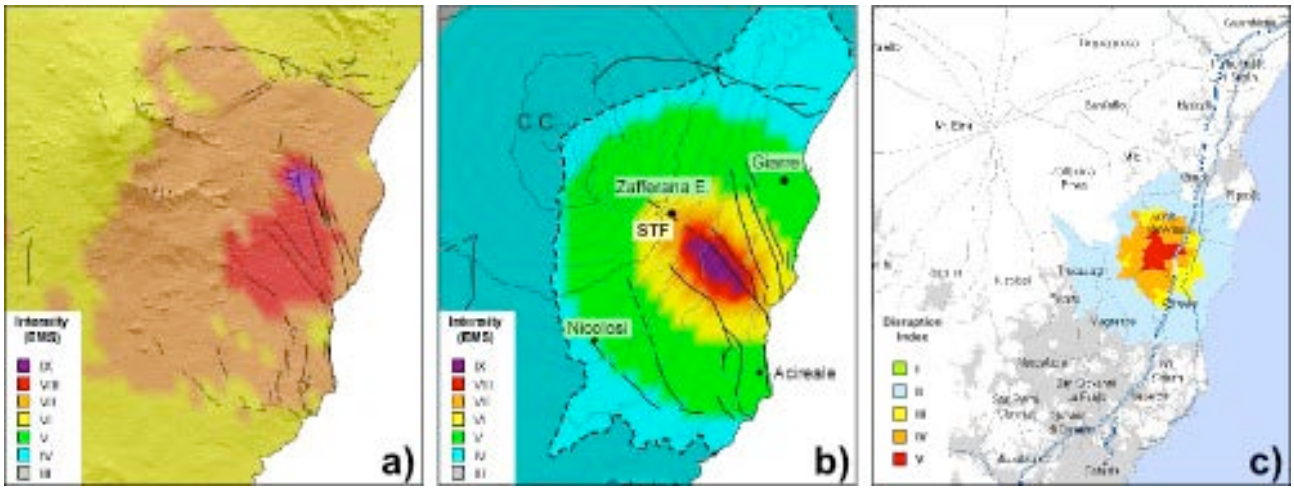

Figure 1. a) Seismic Hazard map: expected intensity at 10% of exceeding probability for 30 years of exposure time. b) Earthquake scenario on STF (S. Tecla fault) for an event with Io IX EMS (dashed line = study area). c) Final level of the Disruption Index.

An example of assessment of seismic risk is based on a scenario earthquake having epicentral intensity IX, the maximum value historically observed at Etna (the 1914 Linera earthquake along the S. Tecla fault) (Figure 1b). Damage at buildings and critical facilities (such as natural gas electricity, water and

waterwastesystems) is estimated through fragility curves from calculated intensity map and then analysed in a spatial series of induced failures. The methodological procedures for the "disruption" operates on this series of consequences and provides an estimate of the global impact, namely the Disruption Index (DI) [Oliveira et al., 2012; Ferreira et al., 2014] (Figure 1c). To compute DI we used QuakeIST, an integrated earthquake simulator developed by IST (Instituto Superior Técnico, Universidade de Lisboa; Mota de Sá et al., 2014)

The above information can drive actions aimed to reduce consequences, or to maintain an acceptable level of risk for future earthquakes. In a context of complexity, where lava-flows or tephra fall-out may occur simultaneously to an earthquake in a small area (municipality), the application of Disruption Index can improve planning and management of "volcanic" emergencies.

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Probability Hazard Map for Future Vent Opening at Etna Volcano (Sicily, Italy)

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Mount Etna is a composite stratovolcano located along the Ionian coast of eastern Sicily. The frequent occurrence of flank eruptions (at an interval of years), mostly concentrated along the NE, S and W rift zones leads to a high volcanic hazard that, linked with intense urbanization, poses a high volcanic risk.

In the framework of the project PON SIGMA (Integrated Cloud-Sensor System for Advanced Multirisk Management), we develop a near real-time computer-assisted analysis and probabilistic evaluations that provides the identification of the areas prone to the highest vent opening hazard. A long-term volcanic hazard assessment, mainly based on the past flank activity of the Mt. Etna volcano, is the basic tool for the evaluation of this risk. Then, a reliable forecast of where an impending eruption will occur is needed.

The use of a code such BET_EF (Bayesian Event Tree_Eruption Forecasting) delivers a long-term hazard map, that, if additional data are provided, switches into a short-term future vent opening map.

The present application is based on incoming seismic and ground deformation data. Analytic inversion of high frequencies deformation data is performed to find the key parameters of a magmatic source in an elastic, isotropic and homogeneous half-space. Seismic data allow us to set the boundary of the investigated area. The inversion is performed by using the genetic algorithms (GAs) approach, a well-known search technique widely used to solve optimization problems and categorized as global search heuristics (Goldberg, 1989). Hence the magmatic source is located, a forward model is computed to evaluate the deformation field over Mt. Etna surface. Therefore, for each cell, the displacement vector modulus is estimated and the density probability function is calculated. A higher probability value matches with the cells with larger modulus, whereas lower estimate is found where the modulus is close to zero, being the sum of the probability values normalized to one over the investigated area.

We modelled the final intrusion of the May 2008 – July 2009 flank eruption at Mt. Etna, whose onset was preceded by an intense seismic swarm and marked by ground deformation recorded at GPS stations.

The future vent forecast highlights the area with higher probability, increasing the difference in relative values between that zone and the rest of the volcano edifice. It is worthy notice that a good accordance is evident if the highest probability area is compared with the real vent occurrence.

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Forecasting Eruptive Activity at Mt. Etna (Sicily): the May 2008 - July 2009 Case Study

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Mt. Etna is one of the most active volcanoes on the Earth, and a population of almost one million of people settle on its flank. Volcanic activity mainly consists of effusive and explosive paroxysmal activity both from its summit craters and new vents opened on the flanks along NE and S rift zones. Many villages and areas have been repeatedly invaded by lava flows during the historical period, posing the volcano hazard vulnerability assessment as a key feature in volcanology. Nowadays, volcanic activity is explored and supervised by an integrating multi-parametric monitoring approach such as to retrieve quantitative probabilistic estimates at both short- and long-temporal window and forecast impending eruptive activity.

A successfully application of this approach was achieved by Brancato et al. (2011, 2012) by applying the BET_EF probabilistic code (Bayesian Event Tree_Eruption Forecasting; Figure 1).

In the framework of the European Project MEDiterranean Supersite Volcanoes (MED-SUV), we show the results of BET_EF application in the flank eruptive activity occurred at Mt. Etna between May 2008 and July 2009. An inventory of seismic data, bulk SO_2 flux, and microgravity collected in the period May 2007 – May 2008, was processed in a novel scenario of concept of inertia time window. Processed data provided outcomes fundamental for making objective and/or false predictions. Results clearly show the fundamental role of the monitoring data in defining key-stages of eruptive sequences, based on identification of thresholds.

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INGV - OE Project of National Civil Service "Volcanoes and Earthquakes in Sicily"

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The National Civil Service (SCN, born in 2001 - Law 64) represents an opportunity for youth, aged between 18 and 28 years, to dedicate a year of their lives in favor of a solidarity commitment and also enables institutions to rely on a team that, stimulated by the possibility of a qualifying experience, guarantees a continuous and efficient service. The SCN intervention areas can be ascribed to the following sectors: assistance, civil protection, environment, heritage and culture, education and cultural promotion, civil service abroad. The Istituto Nazionale di Geofisica e Vulcanologia (INGV) has been accredited by the SCN for Sector B Civil protection and research. In 2013 the Osservatorio Etneo of INGV has promoted a project entitled "Volcanoes and earthquakes in Sicily". The project's activities concern the geological context of the whole Sicilian Region, with a particular attention to the main seismic areas (M. Iblei and M. Peloritani) and to the active volcanoes (Etna, the Aeolian Islands and Pantelleria). The main purposes of geodetic monitoring in volcanic and seismic regions are to recognize phenomena that could represent precursors of the eruptive activity and to characterize the deformation fields. The geodetic monitoring system, run by Osservatorio Etneo of INGV, is performed by a network of sensors, installed in Sicily and Calabria, that can be grouped into permanent and discrete stations networks, for continuous and periodic measurements respectively.

Twelve volunteers are giving their contribution to achieve the specific goals of the project, which includes:

1. The improving the monitoring of volcanoes and seismic areas;
2. Activities of development and maintenance of systems of observation;
3. The improving the quality of produced data;
4. The support to the continuity of data acquisition;
5. Activities with educational ends.

The project activities, divided into five working groups, will now be briefly described:

1. GPS permanent network

The volunteers are involved in a series of tasks that have, as their ultimate aim, the definition of the cause-effect relations between the volcanic activity of Mt. Etna and the movements recorded by the CGPS network, located on the eastern slope of the volcano. They will also participate in all the phases of the acquisition-transmission-processing chain of the CGPS network, in order to learn technical and scientific notions, with the purpose of developing and improving specific aspects of the network.

2. GPS discrete network and remote sensing

The volunteers are responsible for the maintenance and improvement of the geodetic networks and instrumentation, with the periodic review of the geodetic benchmarks, the identification of new sites for continuously improving network geometries and collaboration in implementing mobile stations and section web database; they also have the task to manage, store and process the GPS data of the current and past campaigns relating to the Sicilian Region, converting the files in the universal Rinex format. They will support the execution of geodetic measurement campaigns (EDM and GPS).

3. Geochemical, gravimetric, magnetic networks

The volunteers are involved in monitoring of gas emissions, gravimetric and magnetic anomalies to estimate the state of Mount Etna.

A multi-disciplinal monitoring provides to understand if Etna volcano is in a rest or unrest phase, to evaluate the amount of magma present in the feeding system, and where the potential eruption will take place. These activities are allowed by the use of indirect models performed by specialized software developed by INGV.

4. Petro – Chemical analysis

The volunteers are engaged in the activities of the laboratories of scanning (SEM) electronics, (EDS) and of fluorescence to the X rays (XRF).

5. Management of the informatics structure of the "Sala Operativa" and web services

The volunteers are involved in the Sala Operativa activities, a strategic functional unit for seismic-volcanic monitoring of the Sicilian Region. Their contribution aims to promote the diffusion about the activities carried out by the institute, as well as in the implementation of procedures for the data migration, acquired from different monitoring systems.

The Effect of Crustal Strain on Fluid Circulation in the Mt Etna Aquifers

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On Mt. Etna, tectonic structures drain magmatic fluids towards the surface, producing geochemical anomalies in both the soil gas emissions and the chemistry of groundwater [Brusca et al., 2001; Gurrieri et al., 2008; Cannata et al., 2009]. Variations in fluid circulation (groundwater, gas, thermal fluids) may be caused by variations in both the geodetic and seismic strain, in addition to volcanic activity. In volcanic and tectonic settings worldwide, changes in water circulation (observed as variations of spring outflow or piezometric level in wells) are interpreted as an effect of changes in crustal strain related to volcanic activity or to earthquakes [Shibata and Akita, 2001; Hurwitz and Johnston, 2003; Koizumi et al., 2004; Niwa et al., 2012]. According to the Darcy's Law, the changes in water circulation are strictly related to the variations of fluid pressure gradients, by their own related to the crustal strain. Roeloffs and Linde [2007] proposed the following relationship between the variation of volumetric crustal strain and that of fluid pressure (in the absence of fluid flow), which also includes variations due to changes in the mass of fluid per unit volume. Positive variations of volumetric strain (contraction), as well as the increase of the mass of fluid, induce the increase of fluid pressure and viceversa in case of dilation. Variations of fluid pressure produced by changes of volumetric strain can be directly recorded as changes of water level in wells. The differential change of volumetric strain can thus induce spatial variation of the fluid pressure gradients and, as a consequence, a change in fluid circulation and discharge rates, according to Darcy's law. The time record of geochemical data available on the Etnean aquifer has been analysed. Observed changes have been attributed to variations in fluid circulation, related to variations in the pressure gradients (which cause fluid movement). The comparison with geodetic data in the last 5 years has shown that the periods of variation in fluid circulation parallel those of geodetic strain.

The GPS displacements were interpolated onto an equidistant grid (0.2 km grid spacing) by using two-dimensional splines [Smith and Wessel, 1990], and the geodetic 2D strain tensor was calculated by the using the algorithm described in Deniz and Ozener [2010], then we applied the relation proposed by Roeloffs and Linde (2007) to model the areal distribution of the variation of fluid pressure related to the variation of volumetric strain (the change in fluid mass is not considered for the sake of simplicity). The temporal variation of fluid pressure, averaged over a 1 km-wide sector close to S. Venerina village, are compared with the normalised value of yield and water table head, assumed as a proxy for fluid pressure, recorded in one well and one drainage gallery (located in the same area) and corrected for the effect of rainfall. The significant correlation between modelled and measured values strongly suggests that changes in fluid circulation in the eastern flank can be ascribed to changes in fluid pressure related to crustal strain. This affects also the physico-chemical characteristics of groundwater, as water transfer probably occurs among water bodies with different temperature and composition. The change of fluid paths promoted by the changes of crustal strain likely causes the transfer of water in nearby basins and, as a consequence, a further variation of fluid pressure. This has been observed in other wells in the South-Eastern flank where a significant rise of water levels occurred, which has to be ascribed the fluid mass transfer from nearby basins, induced by dilation strain in this area. This, in turn, can affect rock properties and ground movement, at least at shallow depth, where water circulation is more effective (i.e. at the interface volcanics-clays).

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Kinematics of Mt. Etna's Eastern Fank during Periods of Increased Displacements

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The kinematics of the eastern flank of Mt. Etna is the result of the interplay between two different mechanisms: 1) inflation/deflation cycles of volcanic origin, mainly revealed on the upper eastern flank; 2) a southeastward movement, more evident in the lower eastern flank of the volcano [Bruno et al., 2012]. The southeastward motion has recently shown sudden accelerations, very similar to the ones occurred at Kilauea volcano [e.g. Cervelli et al., 2002] and defined as Slow Slip Events (SSEs). These accelerations can be very hazardous to the densely inhabited lower slopes of the volcano. One of these events occurred between April and May 2009, when the Continuous GPS (CGPS) network of the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, measured displacements in the lower eastern flank that reached values of about 1.5 cm in a single day, in the village of Acitrezza. In the same period, several houses of Acitrezza were severely damaged due to cracks on the walls and were evacuated.

In this work, we analyze the kinematic of the eastern flank of Mt. Etna during the phases of increasing eastward displacements to put into evidence: 1) the repeatability of the ground deformation patterns and of their temporal evolution; 2) the sequential activation of different portions of the eastern flank. Indeed, the principal tectonic lineaments or structures strictly influence the deformations, constraining (or blocking) its propagation and activating the rotation of different sectors of the flank.

For this purpose, we modeled the CGPS position time series of the etnean monitoring network to estimate continuous displacements and velocities for each CGPS station. We then modeled a continuous time-dependent deformation field on Mt. Etna and computed continuous strain rate parameters, as the rotation rate.

The aim of this kind of studies is to highlight transient phenomena in the temporal evolution of ground deformations at Mt. Etna. In particular, the analysis of their repeatability could be a useful tool for a short term forecasting of the displacements that could trigger seismic or other hazardous events.

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SO_2 Flux Monitoring at Stromboli with the new Permanent INGV SO_2 Camera system: a Comparison with Seismological Data

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We installed a permanent SO_2 camera system on Stromboli, Italy, in May 2013, in order to improve the monitoring of SO_2 flux emissions from this volcano. The initial results from the camera show that it is capable of capturing the SO_2 flux emissions associated with explosions on Stromboli, events which are too swift to be captured using the existing FLAME network of scanning UV spectrometers on the island, which are instead optimised for quantifying the quiescent degassing emissions. We found that the explosion gas emissions are strongly correlated with VLP seismic events. There is a variable time lag between VLP event time and increase in gas flux observed by the camera as the explosion gas advects into the field of view of the camera. This variable lag is related to the plume direction, as shown by comparison with the plume location detected with the FLAME network. Comparison of the magnitude of the gas emissions and VLP amplitudes show a correlation, consistent with a gas slug-driven mechanism for VLP production. Further work is needed to fully automate the gas flux calculation using the SO_2 camera.

Real-Time Measurements of Hg0 and H_2S at Solfatara Crater (Campi Flegrei, Southern Italy): an Innovative Approach to Investigate the Distribution of Gaseous Contaminants in Air

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The emission of gaseous contaminants from volcanic and geothermal systems can cause severe concerns for the natural environment and human health, especially in nearby densely populated areas. The Solfatara Crater (Campi Flegrei, Southern Italy) is a hydrothermally altered tuff-cone characterized by intense emission of endogenous fluids from low-to-medium temperature fumaroles and soil degassing. The crater is located within the town of Pozzuoli, thus these volcanic fluids are supposed to have a significant impact on local population. The present study focuses on two potential air contaminants, i.e. gaseous mercury and hydrogen sulfide, which occur in the Solfatara fluids at relatively high concentrations.

Mercury has a strong environmental impact, since it is a toxic pollutant of global impact. Volcanic degassing accounts for a significant part of the natural mercury emissions. Gaseous elemental mercury (GEM or Hg0), the dominant form of mercury in the atmosphere (~98%), is characterized by high volatility and residence time of 1-2 years due to its relatively low solubility and chemical inertness. Hydrogen sulfide (H_2S) quantitatively represents the third-most-prevalent gas species emitted from hydrothermal systems after H_2O and CO_2. It is a toxic acidic gas, as it is irritating and suffocating although it is detectable by humans at very low concentrations due to the distinctive unpleasant odor.

The concentrations of Hg0 and H_2S in the air strongly vary both in time and space, being dependent on meteorological conditions, such as wind, humidity, temperature, as well as on photochemical reactions. According to our approach, real-time measurements of these two gaseous species were carried out within the Solfatara Crater coupling, respectively, a portable Zeeman atomic absorption spectrometer with high frequency modulation of light polarization (Lumex RA-915M) and a pulsed fluorescence gas analyzer (Thermo Scientific Model 450i). The two instruments were synchronized and set to high-frequency acquisition. A multigas analyzer (manufactured by INGV-Palermo) was also used to measure in real-time the CO_2 concentrations. The measurements were carried out along a pre-determined systematic path at walking speed and they were repeated for several days, in order to evaluate the influence of meteorological conditions on the distribution in air of selected gases. The simultaneous acquisition of GPS signal provided the spatial coordinates for the gaseous concentration values. Meteorological parameters were continuously measured using a Davis Vantage Vue weather station located close to the measurement path.

Our results indicate that this approach is highly efficient, providing reliable and reproducible concentrations of Hg0 and H_2S that can be used to construct detailed maps showing the contaminants distribution in air. The method can be thus applied to investigate the behavior of these pollutants released from both natural and anthropogenic sources.

Mercury's Distribution in the Atmosphere, Soils and Plants of the Active Hydrothermal Area of Nisyros (Greece)

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Mercury and its compounds are highly toxic for humans and ecosystems. The dominant form of mercury in the atmosphere is gaseous elemental mercury (Hg0 ~98%), characterized by high stability (residence time 0.5-2 years), low solubility and high volatility. Volcanic and hydrothermal emissions are major natural sources of mercury to the atmosphere.

On June 2013 a multidisciplinary field trip was made on Nisyros island. There, real-time measurements of atmospheric Hg were carried out with a portable Zeeman atomic absorption spectrometer with high frequency modulation of light polarization (Lumex RA-915M). A multigas analyzer (manufactured by INGV-Palermo) was also used to measure in real-time the H_2O, CO_2 and H_2S concentrations in air. The two instruments were synchronized and set to high-frequency acquisition. These measurements were carried out along pre-determined paths at walking speed. The simultaneous acquisition of GPS signal provided the spatial coordinates for each concentration value. Atmospheric Hg concentrations in the atmosphere ranged from 30 to >7000 ng/m^3 within the Lakki caldera, with the highest concentrations close to active fumarolic vents. Background values, outside the Lakki caldera were <15 ng/m3. Furthermore, Hg values showed a good correlation with the other fumarolic gases (H_2O, CO_2 and H_2S) confirming its hydrothermal origin.

During the same field campain, 33 samples of top soils and 31 of endemic plants (Cistus creticus and salvifolius and Erica arborea and manipuliflora) were collected in the caldera area. Moreover, one sample of plant and soil was collected outside the caldera as local background, for comparison. All soil and plant samples were dried at 36o C and powdered avoiding metal contamination. Their Hg content were analyzed with Combustion Atomic Absorbance (CAA).

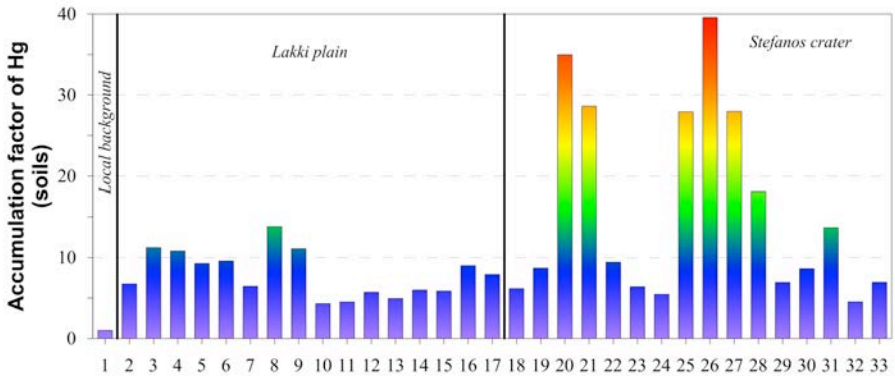

Figure 1. Enrichment of Hg in the soil samples. The values are normalized to the local background value.

The results showed good correlation of S - Hg in almost all the soil samples of Stefanos. Also, high enrichments of Hg are noticeable in the most active fumarolic areas, where the hydrothermal activity is more intense. The concentration in these sampling points varies from 15 to 45 times the concentration of the local background. Similar enrichments were also found in plants. From the comparison between Cistus sp. and Erica sp. we found a significantly higher enrichment and a better correlation with the soil Hg concentrations in the former respect to the latter, making Cistus sp. the most suitable plant for Hg biomonitoring studies at Nisyros.

Pizzi Deneri Field Trips - Etna 2010-2014

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Laboratory exercises, field observations and field trips are fundamental parts of many earth and environmental science courses. In order to integrate theoretical and practical concepts of Earth Sciences, fieldwork plays a key role, representing an opportunity to experiment and evaluate new protocols and techniques which can solve common scientific problems in the field. Since the fieldwork is based on a great deal of research, it is considered to be vital for the development of students and helps them become qualified practitioners in all aspects of these disciplines. Despite the decreasing per capita educational resources in the earth and environmental science departments, both the number of students and the cost of fieldwork have increased.

Here, we present our experience of five summer field trips held on Etna volcano (Italy) conceived, designed and organized as an alternative to formal fieldwork with a reduction in cost. The basic ideas behind the organization were: to share scientific knowledge and experiences, to apply a multidisciplinary approach, to use local resources with a low-cost organization and, at last but not least, to have fun. The logistic base of the field trips was the "Volcanological Observatory of Pizzi Deneri", a picturesque building in a spectacular scenario. The observatory, sponsored by Aaroun Tazieff, was built in 1978 by CNR-IIV International Institute of Volcanology under the direction of Prof. Letterio Villari. It is located at the base of the N-E Crater at an altitude of 2850 m. a.s.l, on the rim of the Ellittico caldera. It lies in a strategic location for access to the summit and is one of the most important sites of the INGV - Osservatorio Etneo for volcanology monitoring and research activities. The participants were undergraduate, graduate, masters and PhD students, post-docs, young and senior researchers working on the scientific themes related to the geochemistry and volcanology. The field trips were organized in collaboration between the University of Palermo, the INGV of Palermo and Catania, the University of Heidelberg and the efforts of many colleagues and friends. The organization was carried out thanks to the support and the willingness of the INGV of Palermo (for the off-road vehicles) and Catania (for the hospitality at the observatory).

Figure 1. Participants to the Pizzi Deneri field trips, Etna 2010-2014.

The field trips were focused on the main ways to study volcanic emissions: direct sampling and remote sensing techniques. Several new instruments were tested for the first time in the field including a new in-situ CO_2 sensor, a new in-situ SO_2 sensor, as well as the application of updated MAX-DOAS instruments and SO_2 cameras. Data collected as a part of the five campaign campaigns carried out since 2010 formed the basis of 6 Bachelor and 5 Master . To date, 5 published article have been published [Aiuppa et al., 2011, Tassi et al., 2012; Tamburello et al., 2013; Pering et al., 2014; Wittmer et al., 2014], one is submitted [Gliss et al. sub], with others currently in preparation and several abstracts were presented at international conferences.

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Aerial Digital Photogrammetry Technique as a Tool for 4D Digital Surface Model: the Example of Etna Summit Craters

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Using multiple view image matching technology in conjunction with digital aerial imagery (digital photogrammetry) allows generation of extremely dense point clouds and subsequent calculation of Digital Surface Model (DSM) of surveyed areas. This technique allows obtaining models comparable to those obtained from state of the art LIDAR technology, although the number and overlap of used images plays a key role in the robustness of generated models; images redundancy can dramatically lower general errors and outlier points in models processing. Digital photogrammetry is a low cost solution to generate DSM over critical areas subject to hazard that needs continuous monitoring. A number of software solutions do exist for digital photogrammetry, designed for both aerial and close-range imagery; a new and widely used software package (Agisoft PhotoScan Pro) is geared toward semi-automatic processing of aerial images with the end goal of the creation of 3D meshes, DEMs and orthophotos. PhotoScan can handle a wide range of digital images, from scanned historical aerial digitized images, up to newest spherical image formats and automatically calculates camera calibrations.

Here we present a Digital Surface Model of the summit area of Etna, calculated using a set of digital images acquired by a spherical camera (Pointgrey Ladybug camera) installed on an helicopter during a geophysical survey flight in May 2012. The DSM obtained will be compared with the Digital Terrain Model (DTM) elaborated by the Cartographic Laboratory (Map-Lab) of the INGV-Osservatorio Etneo [Behncke et al., 2014]. The DTM of Etna summit area was updated with GPS measurements acquired using two GNSS (Global Navigation Satellite System) Leica Zeno 10 sensors combined with laser rangefinder. The GPS measurements were elaborated with GIS software (ArcGIS) in order to reconstruct the morphology of the New South-East crater cone, to map lava flows and to calculate the volume of the volcanic products emitted. All the volcanological parameters extracted from the updated DTM of the summit area of Etna are crucial information for Civil Protection goals.

Considering the advantages of aerial digital photogrammetry technique using spherical images (using spherical images lowers the number of needed photos and consequently acquisition times), it is possible to activate a long term monitoring to model in detail morphology evolution of summit crater area of Etna volcano (4D digital surface model). Furthermore, during an eruptive activity the integration of digital photogrammetry and field survey data could be useful for mapping ongoing lava flows and for calculating the volcanological parametres.

Data Mining Methods for Automatic and Real-Time Recognition of Volcano Activity

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In the recent years, new technologies, such as broad-band seismology, infrasonic microphone networks, satellite observations of ground deformation, high quality video surveillance systems, gas sensors, and advances in computer power and in data transmission, have been contributed to the realization of automatic or semi-automatic data mining software able to recognize volcanic activity by monitoring real-time data coming from sensor networks.

An automatic software monitoring volcano state can be a valuable aid for control rooms where, at the present, the responsibility to evaluate the volcano state is delegated only to researchers. Because of the complexity of volcanic dynamic process and possible failures in some recorded data, precise state assessment is usually not achievable. In the framework of the project PON SIGMA (Integrated Cloud-Sensor System for Advanced Multirisk Management), we proposed a system making probabilistic reasoning to overcome such problems, by using Hidden Markov Models (HMMs), which deals with uncertainties and probabilities. Since RMS (Root Mean Square) of seismic amplitude of volcanic tremor time series is one of the most used parameters to monitor volcano activity for its strong relation with volcano state, this model is based on the study of literal values (tokens) translated from the RMS time series, via Symbolic Aggregate approXimation (SAX) technique.

We tested the proposed approach on data coming from the Mt. Etna (Italy) continuous monitoring networks for the period 2011-2013. The main features of the proposed framework, based on HMMs and SAX, with respect to other automatic systems applied on seismic signals at Mt. Etna, are the use of multiple stations and the static thresholds to well characterize the volcano state. Its application on a wide seismic dataset of Etna volcano shows how it is possible to effectively guess the volcano state. In particular, most of the lava fountains were detected in advance, making the technique very useful for the detection of paroxysmal activities in near real time. Such a method, which can be used also for other volcanoes, can be easily extended by considering other kinds of measurements for a multi-parametric approach.

Real Time Monitoring of the Mt. Etna Volcanic Emissions Using Geostationary and Polar Multispectral Satellite Instruments

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In this work a procedure for the real time monitoring of the Mt. Etna volcanic ash and SO_2 emissions using the multispectral SEVIRI and MODIS satellite measurements is described. SEVIRI, aboard the geostationary EUMETSAT-MSG platform, has 12 channels from VIS to TIR, a spatial resolution of 3x3 km^2 at nadir (about 4x4 km^2 on Etnean area) and a revisit time of 15 minutes. MODIS, aboard the polar NASA-Terra/Aqua platforms, has 36 channels, a spatial resolution of 1x1 km2 and a revisit time of 1 or 2 days (about 4 images per day on Etnean area).

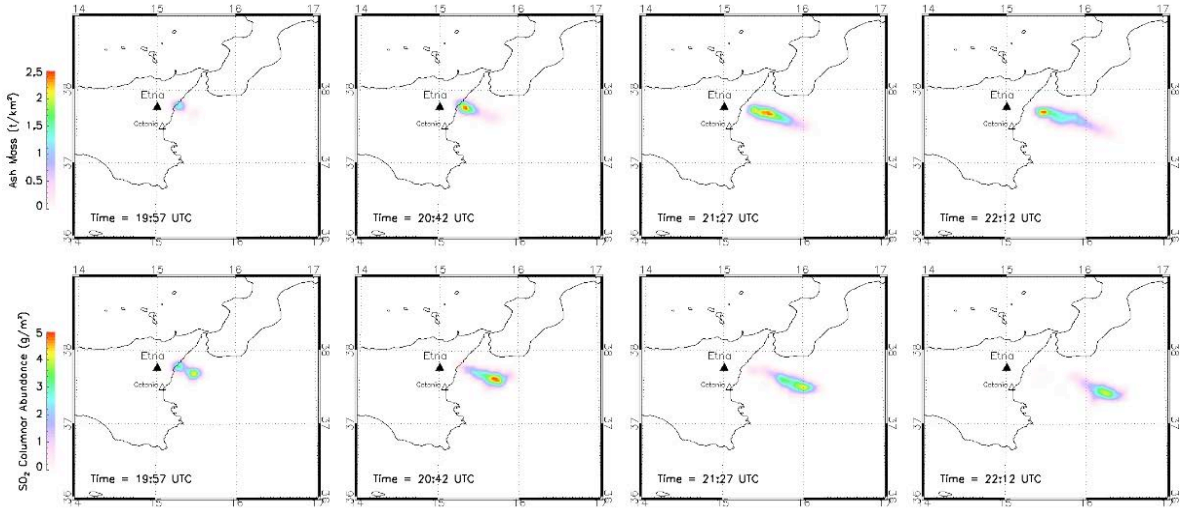

Figure 1. Ash (top row) and SO_2 (bottom row) mass maps retrieved from some SEVIRI images collected during the 23 October 2011 Etna lava fountain event.

The volcanic ash and SO_2 retrievals are realized by using the novel VPR approach [Pugnaghi et al., 2013; Guerrieri et al., 2014] based on the linear interpolation of the radiances surrounding a detected volcanic cloud. The interpolation allows the computation of the plume transmittances in the TIR channels centered around 8.6, 11 and 12 micron further refined with a polynomial relationship obtained by means of MODTRAN simulations adapted for the geographical region, ash type, and atmospheric profiles. From the transmittances the ash mass, AOD, effective radius and SO_2 columnar abundance are obtained. As example Figure 1 shows the temporal evolution of the volcanic ash and SO_2 masses retrieved from several SEVIRI images collected during the 23 October 2011 Etna lava fountaining event. The procedure is also improved by including the retrievals of volcanic water droplets and/or ice mass, AOD and effective radius.

From the sequence of the SEVIRI images, the wind speed and direction at the volcanic cloud altitude can be retrieved. These quantities, together with the masses obtained, allow the reconstruction of the ash and SO_2 fluxes time series at volcano source.

The main advantages of VPR is that it works in real time and that, once the polynomial coefficients are computed, the volcanic cloud altitude and temperature are the only input parameters required to run the procedure. The main drawback is that the surface under the volcanic cloud should be homogeneous enough.

As test case some Mt. Etna (Sicily-Italy) volcano lava fountaining events of the 2011-2013 activity have been analyzed.

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Planning of Laboratory Whole-Rock Dissolution Experiments for Understanding the Dissolution Kinetics of Crystalline Basalts and Basaltic Glasses from Monte Etna (Sicily, Italy)

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The dissolution rates of individual minerals control many geochemical phenomena such as soil fertility, transport and sequestration of CO_2 and influence the chemical and physical nature of our landscape as well as the quality and quantity of potable water [Brantley et al., 2008]. The dissolution rates of individual minerals have been investigated extensively over the past 30 years [e.g., Marini, 2006] but the number of studies reporting the dissolution rates of individual minerals in multi-phase rocks is still lacking [Critelli et al., submitted].

Crystalline basalt and basaltic glass dissolution has been investigated for the possibility of carbon storage in basaltic rocks and to estimate the relative CO_2 consumption capacity for a variety of natural rocks.

In our study, low temperature dissolution experiments at different pH conditions will be performed on a crystalline basalt and a basaltic glass from Mt. Etna.

The dissolution rates of single minerals or rocks is investigated by means of laboratory experiments performed under known conditions of temperature, pH, and composition of inlet solutions using mixed flow reactor systems. A continuously-stirred mixed flow reactor consists of a reaction vessel of known volume, which is continuously stirred with a floating Teflon-coated magnetic stirrer [Pokrovsky et al., 2000]. Stirring is controlled by a stirplate located directly beneath the bath. The inlet fluid is continuously pumped through the reactor at a constant flow rate, Q. The molal concentrations of some relevant solutes, produced by the dissolution of the mineral phases in the rock, are monitored both in the inlet, min, and the outlet fluid, mout. Element release rates are commonly normalized to the initial As,rock, and Ms,rock where As,rock refers to the specific surface area of the whole-rock powder (m^2/g), Ms,rock designates the rock mass present in the reactor (g). The difference between outlet and inlet fluid concentrations at steady state, (1), can be used to calculate the release rate of each element from the rock, ri,rock, ($mol/m^2/s$) using: (2)

$$(1) \quad \Delta m_i = m_{i,out} - m_{i,in}$$

$$(2) \quad r_{i,rock} = \frac{Q \cdot \Delta m_i}{A_{s,rock} \cdot M_{s,rock}}$$

The continuous renewal of the aqueous phase in the reactor helps in maintaining the far-from-equilibrium conditions with the dissolving solid and avoiding precipitation of secondary solid phases.

The central problem in determining individual mineral dissolution rates from a multi-mineral whole-rock element release rate is how to distinguish the contribution of each mineral to the steady-state concentration of a given chemical element which is contained in more than one mineral. The use of triangular diagrams represents a suitable approach to perform the comparison among chemical components in the solid phases and corresponding ratios in the aqueous solutions and helps to distinguish the steady-state solute contribution of the different solid phases in the rock, as shown by Critelli et al. [submitted] for a metabasalt from the ophiolitic sequence of Mt. Reventino (Calabria, S-Italy) [Apollaro et al., 2011].

The combination of the traditional dissolution experiments with the use of triangular diagrams for data interpretation will allow to retrieve the dissolution rates of individual minerals of the crystalline basalt of Mt. Etna and to compare its dissolution behaviour with that of the basaltic glass. Data available in the geochemical literature for other basalts represent an useful reference.

We hope that the results obtained in this study will be of interest to understand the rock-to-water transfer of chemical elements during water-rock interaction processes, including the dissolution of volcanic ash driven by rainwater and lung fluids, thus providing a contribution to quantify the impact of Mt. Etna volcanic eruptions on the environment and humans.

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Volunteers of National Civil Service at INGV: Contribution for Volcanic Outreach Activities

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INGV accredited with the National Civil Service since 2011 and has subscribed its ethical commitment describing values, goals, rights and responsibilities of the volunteers. The aim is to involve young generations in "homeland defense" that is in social services which enforce the relationships between people, territory and living. Volunteers will spend one year fully involved in the activities of the organization, taking the opportunity to grow up, perform a real work experience and learn by doing. Among the projects funded in 2014 there is the project "Science and Outreach: a comprehensive approach to the divulgation of knowledge of Earth Sciences", designed by the LaboratorioDivulgazioneScientifica e AttivitàMuseali of INGV, Roma. The project, dedicated to initiatives of earth sciences outreach, started in May 2014 and will last one year. Among its aims: 1) to contribute to the increase and the diffusion of a correct and informed scientific culture especially with regard to seismic and volcanic phenomena; 2) to extend to cultural associations, universities and citizens, scientific information on events for wider dissemination of basic information and for a correct approach to geophysical issues; 3) to extend the dissemination of scientific information on the Web and social media.

Figure 1. Example of creating volcanic cone that will make the children at the end of the laboratorial activity.

To achieve these objectives, the project involves an initial part of general and specific training, a phase of planning and sharing of the activities, the formation of working groups, and a part of the activities in which the volunteers are included. From the point of view of volunteers there is a wide series of motivation including: increase knowledge in the field of science communication to share with the public; acquire specific skills to improve communication between the research organization and the citizen.

The volunteers are involved in different activities including educational courses and workshop with schools. The events take place in Rome and in other cities, i.e. “ScienzaAperta” (Open Science), “European Researchers Night”, “Science Festival in Genoa”, “Settimana del Pianeta Terra (Week of Planet Earth). “Week of Planet Earth” is an initiative of Federazione Italiana Scienze della Terra (Italian Federation of Earth Sciences), which takes place every two years in Italy with the aim to raise awareness in society about the importance of Geosciences. For this event volunteers take the chance to play an active role in the definition of outhreach proposal,bringing into practice the experience gained in the training phase. They designed laboratorial activities for primary school students with the aim to create an attaching and exciting experience through interactive hand-on methodologiesto engage children in the “amazing” world of Volcanology. Children can imagine scenarios that can occur when a volcanic eruption occursanddevelop awareness on potential volcanic risk. The activity is composed of three phases: first phase, description of volcanic characteristics (how they form, type of eruptions, volcanic products);second phase, hand-on and practical activities including simulation of explosive and effusive “eruptions”; final phase, children will build their own volcanic cone to bring home as a souvenir of the day spent in contact with the world of volcanology.In additionstill for young audience, volunteers created marionettes’ theatre,set on volcano slopes, named “The Fantastic Four Elements”(i.e. earth, water, fire, air) with the aim to illustrate the importance that elements have in their lives. The intent is to use story telling in a playful way to explain geophysics as a whole and provide a sight of the Earth Planetas a fragile and complex system in which elements are interrelated andinter-dependent.

Thanks to the variety of skills and expertise, the group of volunteers is able to interact with the audience and to stimulate interest and curiosity in Earth Sciences from different perspectives.

A new M_L-M_D Relationship for Mt. Etna Earthquakes (Italy)

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Studies on seismicity at Mt. Etna are of extreme importance for the high seismic and volcanic risk which characterizes the area. In this region, seismic events are mainly located at less than 5 km b.s.l. depth, producing arrivals with medium-to low-frequency content and/or complicated signatures at stations just a few kilometers distant from the epicentral area [Patanè and Giampiccolo, 2004]; on the other hand, earthquakes which present high frequency content and sharp arrivals, similar to those of typical earthquakes of tectonic areas, are mainly located between 5 and 20 km.

Seismicity mainly occurs in the form of swarms, whereas foreshock-mainshock-aftershock sequences are rarely recorded, and seldom exceed magnitude 4.0 [Ferrucci and Patanè, 1993].

In volcanic areas the calculation of the local magnitude M_L is more objective than that of M_D because the measurement of the signal amplitude is less ambiguous with respect to the decay of the earthquake coda, which may be masked by the presence of noise, volcanic tremor, or other shocks [Del Pezzo and Petrosino, 2001; D'Amico and Maiolino, 2005]. Therefore, since magnitude estimation in M_D and M_L, although mutually related, do not produce the same results, it is mandatory to adopt an empirical conversion to produce a homogeneous catalogue for Mt. Etna region.

The Standard Linear Regression (SLR) is the simplest and most commonly used regression procedure applied in literature [Gasperini, 2002; Bindi et al., 2005]. However its application without checking whether its basic requirements are satisfied may lead to wrong results [Castellaro et al., 2006]. As an alternative it is better to use the Orthogonal Regression (OR) relation [Carrol and Ruppert, 1996], which assumes a different uncertainty for each of the two variables [Lolli and Gasperini, 2012].

Investigating the performance of different regression procedures commonly used to convert magnitudes from one type into another one, is also an operation which has strong influence on the slope of the frequency-magnitude distribution (the b-value of the Gutenberg-Richter). In particular, the frequency-magnitude distribution can be heavily biased when calculated on magnitudes converted from various scales. By contrast, it is possible to obtain unbiased estimates of a and b values by converting magnitudes through OR. The application of OR requires the estimate of the ratio between the dependent and the independent variable variances, and when only the ratio variance is known, the OR represents the simplest and mostly used approach.

A database of magnitude observations recorded at Mt. Etna during the period 2005 – 2012 is used for this study [Gruppo Analisi Dati Sismici, 2013]. The new M_L-M_D relationship obtained by applying the OR is:

$$M_L=1.237(\pm0.009)M_D - 0.483(\pm0.016)$$

with a correlation coefficient R=0.90 and rms between observed and calculated M_L of 0.27. The superiority of the OR relation over the SLR has been demonstrated on the basis of the best fitting between regression line and data distribution.

The M_L-M_D relationship obtained significantly reduces the previous bias between M_L and M_D estimated for earthquakes recorded at Mt. Etna and will be used for the purpose of catalogue homogenization.

We conclude that the commonly used SLR may induce systematic errors in magnitude conversion; this can introduce apparent catalogue incompleteness, as well as a heavy bias in estimates of the slope of the frequency–magnitude distributions.

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Trace Elements in Soils and Plants from the Active Hydrothermal Area of Nisyros (Greece)

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The trace element loading in soil is a function of the parent material plus subsequent atmospheric or water-borne deposition. The mobility, solubility, speciation and bioaccumulation of trace elements depend on various factors, as well as on theirgeochemical properties. Mobility can be favoured by a strongly acidic environment. In volcanic environments, significant amounts of trace elements discharged from gas emissions, contribute to produce air particulate. Nisyros Island, a stratovolcano located along the South Aegean active Volcanic Arc, is characterized by intense hydrothermal activity in the Lakki caldera. In particular, the fumaroles located in the craters of Stefanos, Kaminakia, Lofos Dome and the area comprising Phlegeton, Polyvotes Micros and Polyvotes Megalos discharge hydrothermal fluids rich in H_2O (91– 99%), CO_2 and H_2S. Their temperatures are almost 100° C and H_2S accounts for up to 26 % of the released dry gasphase.

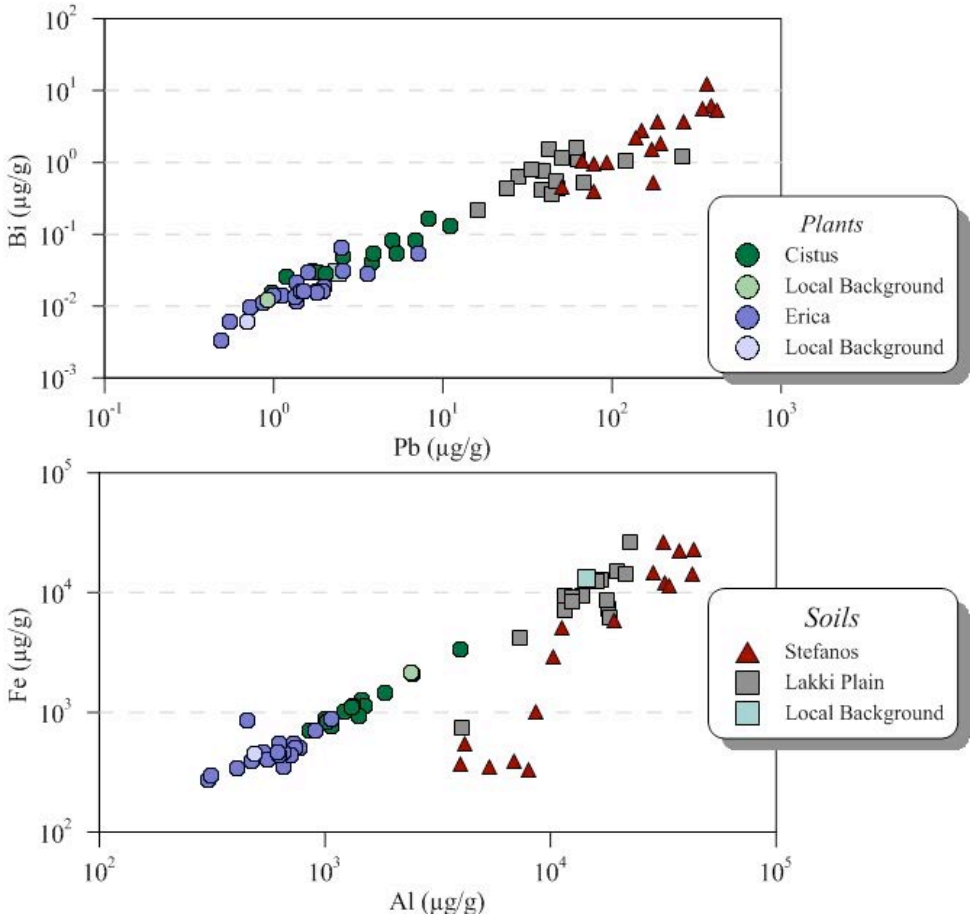

Figure 1. Binary plots showing the concentrations of Bi and Pb (a) and Fe and Al (b) in soil and plant samples. Note that plants were not present in the Stefanos crater.

On June 2013, during a multidisciplinary field trip on Nisyros island, 33 samples of top soils and 31 of endemicplants (Cistus creticus and salvifolius and Erica arborea and manipuliflora) were collected in the caldera area, to determinate the main mineralogical composition and to investigate the distribution of trace elements concentrations and the possible relationship to the contribution of deep originated fluids. Moreover, one sample of plant and soil was collected outside the caldera as local background, for comparison. All the soil samples were powdered avoiding metal contamination and the mineralogical composition was determinated via XRD analysis. Chemical composition of the soils was analyzed with two different extraction methods: microwave digestion (HNO_3 + HCl) and leaching with de-ionized water. The leaves of plants were gently isolated, dried and powdered for microwave extraction (HNO_3 + H_2O_2). All the solutions were analyzed for major and trace elements contentsby using ionic chromatography (IC) and inductively plasma spectrometry (ICP-MS and ICP-OES).

The results showed a good negative correlation between S concentration and pH, testify for the effect of H_2S degassing at the crater areas. H_2S, which is one of the main components of the fumarolic gases at Nisyros, in the shallow oxidizing environment produces great amounts of H_2SO_4 in the soils. The active fumarolic area (Stefanos) shows the lowest pH values (1.9 - 3.8), the samples collected in the remaining area within the Lakki Plain shows somewhat higher values (4.2 - 5.8) while the background soil has a neutral pH. In the majority of the Lakki Plain soils the main mineralogical composition is Quartz, Feldspar and Gismondine whereas in the Stefanossoils, because of the lower pH and the higher temperatures, the main composition comprises mostly hydrothermal alteration minerals. Moreover,high enrichments of many trace elements were noticed both in plants and soils respect tothe local background, in particular for Tl, Rb, Zn, Mn, As, Pb, Se, Te, Rb, Bi, Al. The highest concentrations were found both in soils and plants close to the most active fumarolic areas and also close to the Geothermal exploration well. Moreover, both soils and plants showed a good correlation between Cu-Zn, Cu-Pb, Bi-Pb, Ba-Sr, Bi-Tl, Ti-Al, Ni-Al, Tl-As, Te-Tl, Te-Se as well as REE's. From the comparison between Cistus sp. and Erica sp. we found a significant enrichment in the former respect to the latter, making Cistus sp. the most suitable plant for biomonitoring studies at Nisyros.

Review of Ten Years of Volcano Deformations Recorded by the Ground-Based InSAR Monitoring System at Stromboli Volcano

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Stromboli volcano (Southern Italy) is one of the most monitored volcano in the world with a surveillance network that includes a permanently sited ground-based SAR interferometer (GBInSAR). The analysis of the entire dataset of GBInSAR measurements allowed the assessment of the deformation field of the northern part of the summit crater area and the Sciara del Fuoco depression. In details, the main displacements recognized can be related to different factors: 1) the inflation/deflation respectively immediately before and after each new effusive event; 2) the bulging of localized sectors of the volcano involved in the vent opening; 3) the gravitational sliding of the Sciara del Fuoco infill; 4) the movement of lava flows. Accelerations in this sector are related to sheet intrusions, while the possibility of vent opening, associated with small sliding, or catastrophic flank failure are related to highly overpressurized sheets, able to produce high displacement rate in the Sciara del Fuoco.

In the summit crater area, the increases in the displacement rate are related to the pressurization of the shallow conduit system, as the consequence of the variation in the magma level (magmastatic pressure) or to the lateral magma migration (lateral conduit expansion or dike intrusion) in response to the increase of the overpressure component. Fluctuations in the displacement rate in the summit crater area can be related to the magma overturning within the conduit, with the increases in displacement rate during the upwelling of less dense magma, while displacement rate decreases as the degassed magma column is pushed out from the conduit (lava flows or overflows). Instead, the decrease in the displacement rate without coeval lava outpouring could be related to the sink of the degassed magma due to density contrast between the gas-poor and the gas-charged magmas. Using the displacement rate in the summit crater area as a proxy for the variation in the pressure condition in conduit (both magmastatic and overpressure components), thresholds for the crises characterized by the occurrence of overflows (eventually associated with major explosions) and flank effusions (eventually associated with paroxysmal explosions) are identified. Small conduit overpressure will produce overflows (sometimes associated with crater-rim collapses), while large magma overpressure will laterally expand the conduit forming NE-SW striking sheets, feeding eruptive vents at the base of the summit crater area and within the Sciara del Fuoco, generating conditions of instability that can evolve into catastrophic collapse of the instable flank.

Volcanic Processes Detected by Tiltmeters: a Review of Experience on Sicilian Volcanoes

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We report a review of the experience gained in the use of tiltmeters on Mt.Etna, Stromboli and Vulcano during last 30 years.

Tilt data represent a fundamental contribution towards understanding volcanic processes such as dike intrusions, fracture propagation, lava fountains and volume changes in magmatic or hydrothermal systems causing a deflation/inflation of the edifice.

Highly sensitive instruments, accurate and deep (> 10-15 m) installations and a network geometry that comprises some stations close to the summit area are the main elements to achieve a successful volcano tilt monitoring.

Intrusive processes preceding lateral eruptions show large variations (up to over 100 microradians), while minor variations (not exceeding 2.5 microradians) are linked to lava fountains that form ash plumes and lead to fallout deposits that cause severe hazards to aviation. High precision tilt also allow detecting the slight ground deformation linked to strombolian activity (0.01-0.2 microradians) as well as co-seismic variations (0.1-1.5 microradians) and tidal effects (0.1-0.2 microradians) that may have a role in the evolution of a volcanic system.

Time-amplitude tilt ranges linked to each process are generally different allowing to discriminate, in real time, between a signal associated to one process and another one.

This fact reveals as tiltmeters have a very important role in the realization of a real-time system, able to provide warnings to those living on the volcano slopes.

Improving the Monitoring System in the Marine Sector of Campi Flegrei Volcanic Area

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The marine sector of the Campi Flegrei caldera has started to be monitored over the long-term with a seafloor equipment deployed in the Gulf of Pozzuoli from 2008. The equipment includes a set of geophysical, oceanographic and environmental sensors integrated in a marine platform that was specifically designed for real-time monitoring. This platform, named CUMAS (Cabled Underwater Multidisciplinary Acquisition System), was installed in the center of the Gulf at about 2.5 km south of Pozzuoli where the sea depth is about 100 m [Iannaccone et al., 2010]. The CUMAS system consists of a seafloor module connected by cable to a buoy (elastic beacon type) equipped with autonomous power supply systems, real-time data-transmission devices and a weather station. The core of CUMAS is the seafloor module that contains geophysical and oceanographic sensors, in particular, a three-component broadband seismometer, a best in class three axis MEMS accelerometer, a low-frequency hydrophone and a high-resolution sea bottom pressure recorder. A single-point acoustic, three-component, water-current meter and a water-temperature sensor were also installed to monitor some water local physical parameters. A set of status sensors, which also included a digital compass and a two-component digital tilt-meter, were added to track the attitude of the module over the course of the experiment. The marine monitoring system transmits the data in real-time and is integrated into the Monitoring Center in Naples managed by INGV-Osservatorio Vesuviano.

A continuous GPS station has been installed since the end of 2011 on the top of the buoy. The elastic beacon buoy forms a structure which is rigidly connected by a mechanical cable to the ballast on the sea bottom, a submerged float at the base of the buoy maintains tension on the cable and ensure the overall buoyancy of the system. In this way, any vertical movement of the seafloor propagates rigidly to the emerged part of the buoy itself, allowing measurement of the vertical movement of the sea floor by the GPS station. The analysis of about 17 months of continuous GPS data, from January 2012 to May 2013, revealed an overall uplift of about 3-4 cm allowing a first measurement of vertical seafloor displacement in the Campi Flegrei caldera [De Martino et al., 2014].

A new opportunity to enhance the deployed system was given by a national project, EMSO-MedIT, which is providing the necessary resources to expand the data acquisition to other areas of the Gulf of Pozzuoli. New improved systems similar to CUMAS are going to be deployed in three additional marine sites of the Gulf of Pozzuoli and the existing tide gauges network will be renewed with state-of-art sensors. The overall new monitoring infrastructure will allow to extensively map the seafloor vertical displacement and to improve the interpretative models of the bradyseism phenomenon including a more accurate location of earthquakes in the marine areas and extending to lower magnitude values the detection of the seismic activity.

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The 2014 Eruption at Stromboli Volcano (Italy): Volcanological Assessments Inferred by the Geochemistry of Hydrothermal System

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Stromboli island (Italy) is an open conduit volcano characterized by a strong volatiles degassing from the crater vents and from the soil and by the presence of a thermal aquifer fed by volcanic fluids. The first step in a geochemical surveillance programme is the chemical and isotopic characterization of the fluids emitted from the volcanic system, that includes fumaroles, thermal waters and soil degassing points. In many volcanic systems, the safe access to the high temperature vents is not feasible. In such cases, the cold and thermal waters circulating on the flanks of the volcano may represent the only observation points from which we can get information about the state of activity.

The geochemical monitoring program carried out during the last 12 years consisted in the periodic monitoring of the chemical and isotopic composition of peripheral thermal groundwater [e.g., Rizzo et al., 2009]. In detail, we performed a routine sampling (and subsequent laboratory analysis) of six thermal wells located within the village of Stromboli. One of these wells (COA) was specifically drilled for the geochemical monitoring [Inguaggiato et al., 2011]. The geochemical approach utilized in this work is based on the study of dissolved He and CO_2 in ground-waters circulating on the volcanic edifice.

Discontinuous monitoring of PCO_2 of thermal waters of Stromboli

The amount of dissolved CO_2 measured in thermal wells throughout 2007-2014 did not show any significant change attributable to the volcanic activity of Stromboli, with the exception of COA well. This is probably due to the geometry of the hydrothermal aquifer and the peculiar location of this well. Considering that Stromboli is characterized by persistent strombolian explosions, sporadically interrupted by major events, a discontinuous sampling of thermal waters can only reveal long-term variations that are linked to changes of the total pressure exerted by the plumbing system on the hydrothermal aquifer. We point out that only COA well showed these significant changes, with an increase of the dissolved CO_2 from 60 to 200 cc/l STP, recorded from the end of the eruption 2007 to mid-2010. After a slight decrease of dissolved CO_2 (around 90 cc/ l STP) recorded in December 2010, a new increasing trend (up to values of about 180 cc/l STP) was observed in April 2013. The behavior of CO_2 content dissolved in the thermal aquifer was parallel to the anomalous degassing of CO_2 from the soil at the summit of the volcano [Inguaggiato et al. 2014], supporting the hypothesis of a continuous pressurization of the Stromboli volcanic plumbing system. Unfortunately, the discrete sampling of COA well stopped in 2013 due to technical issues, that did not allow to monitor the period preceding the onset of 2014 eruption.

Helium isotopic composition of thermal waters of Stromboli

More detailed information on the origin of fluids at Stromboli and on the evaluation of its volcanic activity could be inferred by the isotopic composition of helium dissolved in the waters [Inguaggiato and Rizzo, 2004]. A long term monitoring of $^3He/^4He$ ratio is carried out since 2000, that allowed to record interesting variations related to magma dynamics at depth during 2002-2003 and 2007 eruptions. The highest 3He/4He ratios (up to 4.55 Ra, being Ra the $^3He/^4He$ ratio in atmosphere) were recorded during the strongest period of unrest, coincident with effusive activity and/or major explosions [Rizzo et al., 2009]. The 2014 effusive eruption, started on August 7 and still ongoing at the submission date of this abstract, was preceded by an increase of $^3He/^4He$ ratio that reached values as high as 4.55 Ra during the crisis. We infer that this new variation is compatible with the degassing of a new and more primitive magma at depth, that reasonable triggered the summit instability and the eruption onset.

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The Ongoing 2014 Effusive Eruption at Stromboli Volcano: Volcanological Assessments Inferred by Soil Degassing from Summit and Peripheral Areas

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The Stromboli volcano, the more active of the Aeolian Archipelago, is characterized by an open conduct degassing system with a continuous explosive activity every 20-30' named "Strombolian activity". Occasionally more 'loud energetic explosions occur associated with lava emission. The recent effusive activities occurred in 2002-2003 and 2007; the last one began in February 2007 and ended in April 2007. On 7 August, 2014 started a new effusive eruption from an opened fracture on the Sciara del Fuoco flank at 600 m a.s.l..

Continuous monitoring of soil CO_2 degassing in the summit area of Stromboli

Geochemical investigations carried out on volcanic areas demonstrate that the study of the variations of extensive parameters, like output of mass and energy, are very important to monitor the volcanic activity [Inguaggiato et al., 2011, 2013]. Since July 2000, continuous measurement of CO2 fluxes emitted from the summit soil at the Pizzo sopra la Fossa (STR02) has been carried out with hourly frequency by means of an automated accumulation chamber (manufactured by West Systems ltd.). Data are transmitted to the COA Civil Defence volcano observatory at Stromboli via a radio link (STR02), whereby it is sent to the INGV-Palermo geochemical monitoring centre through a virtual private network link.

The STR02 monitoring station of soil CO_2 fluxes installed on the summit area of Stromboli provided useful information on the state of volcanic activity and the regime of degassing from soils. In particular the long time series of CO_2 fluxes acquired in 1999-2008 led to the identification of classes of degassing that have been associated to the regime of degassing and the state of volcanic activity of Stromboli. Based on the long-term data record and their relationship with the coeval volcanic activity, we have identified three families of soil CO_2 degassing, Low, Normal and High [Inguaggiato et al, 2011]. The three classes of degassing are identified as follows: below 4000 g m^{-2} d^{-1}; between 4000 and 10000 g m^{-2} d^{-1}; higher than 10000 g m^{-2} d^{-1}.

In 2010, the volcanic activity of Stromboli has been characterized by a "normal Strombolian" activity interrupted only by two major explosions recorded respectively in the first days of 2010 and at the end of June. The data of soil CO_2 fluxes in the 2011-2012 period showed a sustained degassing with daily average values generally higher than 10,000 g m^{-2} d^{-1}. Between the end 2012 and early 2013, a new trend of increase of soil CO_2 flux was recorded with fluxes as high as 20,000 g m^{-2} d^{-1}. In the period 2012-2013 the volcanic activity of Stromboli has been characterized by an increasing strombolian activity interrupted by several "major" explosion and culminated in November 2012-February 2013 with lava overflow from the summit craters. The second half of 2014 was characterized by background values around 7000 g m^{-2} d^{-1} that is in agreement with the opening of the fracture at 600 m on the Sciara del Fuoco. Magma drainage from the fracture implies the lowering of the magma column and the decrease of the magma volatiles in the upper part of the volcanic conducts.

CO_2 output variations recorded in the summit and peripheral areas

Three soil CO_2 campaigns were carried out in the period 2007-2013 to estimate the total output discharged from the summit area of Stromboli (where the STR02 station was installed). About 50 points of soil CO_2 fluxes measurements were performed during each survey. These measurements were made on the summit area, including the zone of STR02 soil CO_2 station, covering a surface of about 67500 m^2. The total CO_2 output of the 2013 campaign, estimated on the basis of sGs methodology, showed a maximum value of 47 t d^{-1} doubled with respect to the value measured in the same area in 2010 (26 t d^{-1}). Moreover, the zone of STR02 soil CO_2 station show a wider anomaly with respect to the previous campaigns. The increased CO_2

output data recorded in the 2013 campaign corroborates the CO_2 fluxes measured by the station (STR02) that are characterized by average fluxes above 10000 g m^{-2} d^{-1} for the entire 2011-13 period, doubled with respect to 2010.

In the same period of observation, three campaigns for the measurement of soil CO_2 were also carried out to estimate the total output discharged in a peripheral area of Stromboli (Scari) in the period 2007-2014.

The total CO_2 output of the September 2014 campaign, estimated on the basis of sGs methodology, showed an increase of about one order of magnitude with respect to the measured value for the same area in 2010. The increase of CO_2 degassing in the peripheral area suggests the pressurization of the peripheral plumbing system, as also confirmed by the high PCO_2 in the thermal aquifers and by the very primitive value of the isotopic values of dissolved helium recorded in the 2014.

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Comparison between Mechanisms of CO_2 Degassing from El Chichón Volcanic Lake - México and Specchio di Venere Lake - Pantelleria, Italy

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We present results of the CO_2 diffuse emission from the surface of two volcanic lakes: El Chichón (EC) in Mexico and Specchio di Venere (SV) on Pantelleria Island, Italy. Both lakes are drainless, have similar sizes (~2x105 m^2) and similar input-output dynamics. However, they are drastically different in water chemistry. The SV lake is alkaline (pH >9) and of a high near constant salinity, whereas EC lake is acidic (pH 2.3) and of a low variable salinity. In the vicinity of both lakes there are thermal grounds with steam vents and hot springs and a high CO_2 soil flux. The SV lake has high alkalinity (~70 meq/L), whereas the EC lake is characterized by high concentration of dissolved CO_2 [Taran et al. 1998; Favara et al. 2001; Aiuppa et al. 2007; Mazot & Taran, 2009; Mazot et al. 2011; Madonia et al. 2013].

CO_2 flux measurements from the surface of both lakes were made with the "floating" accumulation chamber [Chiodini et al. 1998]. During the flux measuring, gas samples were taken for carbon isotopic analysis. Soil flux measurements were also made in the crater of El Chichón volcano and on the area adjacent to the SV lake.

The preliminary results of CO_2 fluxes indicate EC lake has a high CO2 flux with a mean value of 3500 g m-2 d-1, with the highest values alignment across NW-SE and NE-SW faults and a high degassing by bubbling gases, especially near the strongest NE fumarolic field. While SV has a mean value of the CO_2 flux~ 10 g m-2 d-1 and limited bubbling on the lake surface. High CO_2 flux was measured from the soil near the lake at the Mofeta place. A net mean diffusion flux (without bubbles) from EC lake is about 350 times higher than that from SV lake (3500 g m^{-2} d^{-1} vs 10 g m^{-2} d^{-1}). SV has the total CO_2 flux by diffusion of ~2.5ton d-1 from an area of 0.2 km2 and the total flux of 0.44 ton d-1 by bubbling areas at SW and S zones. The EC lake has the total CO_2 flux of 840 ton d^{-1} from an area of 0.24 km^2. The total CO_2 output from SV is nevertheless about two times higher taking into account the seepage from the lake (~ 8 kg s^{-1}) of highly carbonated water.

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Short-Term Impending Eruptive Activity at Mt Etna Revealed from a Multistation System based on Volcanic Tremor Analysis

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Over fifty eruptive episodes with Strombolian activity, lava fountains, and lava flows occurred at Mt Etna volcano between 2006 and 2013. Namely, there were seven paroxysmal lava fountains at the South-East Crater in 2007-2008 and 46 at the New South-East Crater between 2011 and 2013. Lava emissions lasting months affected the upper eastern flank of the volcano in 2006 and 2008-2009. Effective monitoring and forecast of such volcanic phenomena are particularly relevant for their potential socio-economic impact in densely populated regions like Catania and its surroundings. For example, explosive activity has often formed thick ash clouds with widespread tephra fall able to disrupt the air traffic, as well as to cause severe problems at infrastructures, such as highways and roads.

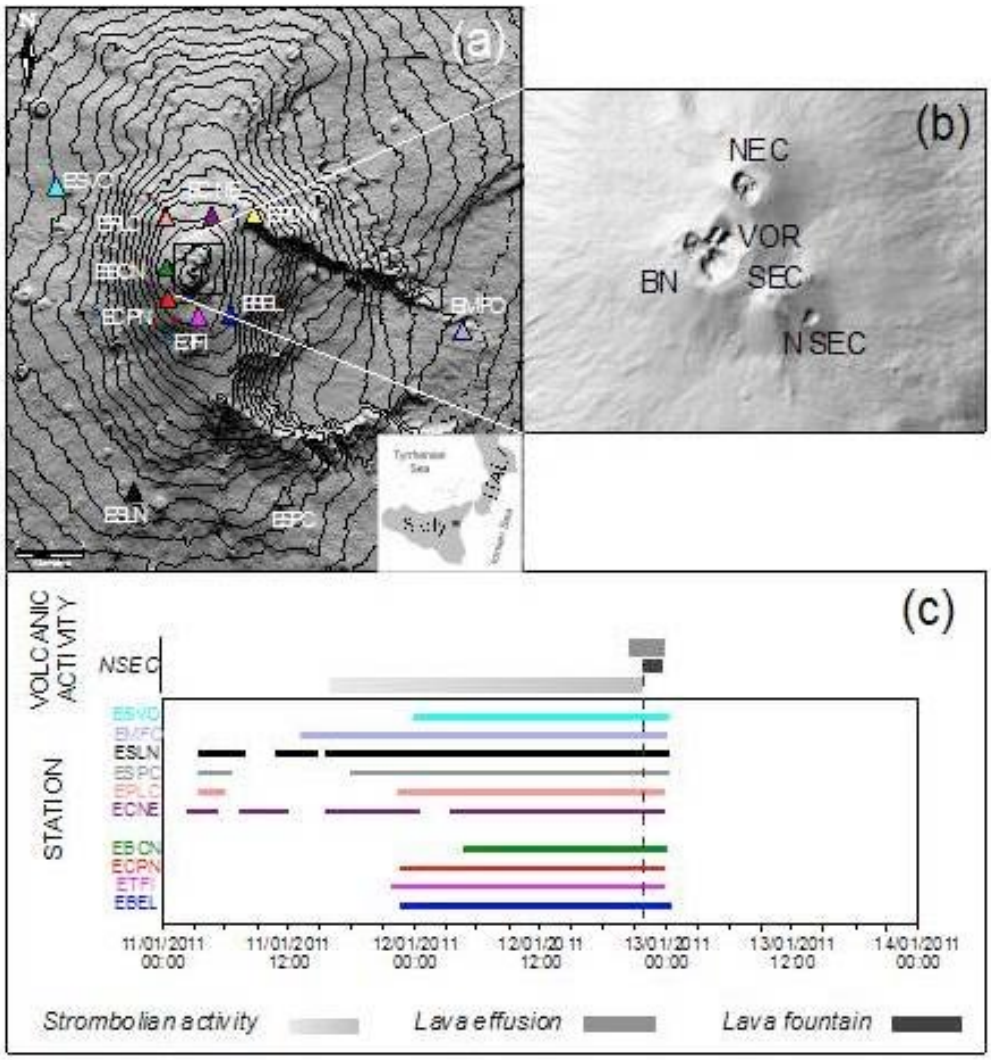

Figure 1. a) Seismic stations on Mt Etna. b) Craters: NEC, SEC, NSEC (North-East, South-East, New SE Crater); BN=Bocca Nuova; VOR=Voragine. c) Alarms flagged during an unrest. Bars on top mark different activity. Dashed line marks onset of the lava fountain.

Timely information about changes in the state of the volcano and possible onset of dangerous eruptive phenomena requires efficacious surveillance methods. The analysis of the continuous background seismic signal, the so-called volcanic tremor, turned out of paramount importance to follow the evolution of volcanic activity [e.g., Alparone et al., 2003; Falsaperla et al., 2005]. Changes in the state of the volcano as well as in its eruptive style are usually concurrent with variations of the spectral characteristics (amplitude and frequency) of tremor. The huge amount of digital data continuously acquired by INGV's broadband seismic stations every day makes a manual analysis difficult. In order to tackle this problem, techniques of automatic classification of the tremor signal are applied. In a comparative study, the robustness of different methods for the identification of regimes in volcanic activity were examined [Langer et al., 2009]. In particular, Langer et al. [2011] applied unsupervised classification techniques to the tremor data recorded at one station during seven paroxysmal episodes in 2007-2008. Their results revealed significant changes in the pattern classification well before the onset of the eruptive episodes. This evidence led to the development of specific software packages, such as the program KKAnalysis [Messina and Langer, 2011], a software that combines an unsupervised classification method (Kohonen Maps) with fuzzy cluster analysis. The operational characteristics of these tools - fail-safe, robustness with respect to noise and data outages, as well as computational efficiency - allowed on-line processing at the operative centre of the INGV-Osservatorio Etneo in 2010 and the identification of criteria for automatic alarm flagging. The system is hitherto one of the main automatic alerting tools to identify impending eruptive events at Etna.

The software carries out the on-line processing of the new data stream coming from two seismic stations, merged with reference datasets of past eruptive episodes. In doing so, results obtained for new data are immediately compared to previous eruptive scenarios. Given the rich material collected in recent years, we are able to apply the alert system to eleven stations at different elevations (1200-3050 m) and distances (1-8 km) from the summit craters. Critical alert parameters were empirically defined to obtain an optimal tuning of the alert system for each station. To verify the robustness of this new, multistation alert system, a dataset encompassing about eight years of continuous seismic records (since 2006) was processed automatically using KKAnalysis and collateral software off-line. Then, we analyzed the performance of the classifier in terms of timing and spatial distribution of the stations. As an example, Figure 1a depicts the location of the seismic stations that were operative during an episode of eruptive activity evolving in paroxysm in 2011 [Behncke, 2011; INGV, 2011a, b]. Different colors allow us to follow the temporal order of triggers (Figure 1c). We also investigated the performance of the new alert system based on KKAnalysis in case of activation of whatever eruptive centre. Intriguing results were obtained in 2010 throughout periods characterized by the renewal of volcanic activity at Bocca Nuova-Voragine and North-East Crater, and in the absence of paroxysmal phenomena at South-East Crater and New South-East Crater. Despite the low-energy phenomena reported by volcanologists (i.e., degassing, low-to moderate explosions), the triggered alarms demonstrate the robustness of the classifier and its potential: i) to identify even subtle changes within the volcanic system using tremor, and ii) to highlight the activation of a single eruptive centre, even though different from the one for which the classifier was initially tested. It is worth noting that in case of activation of weak sources, the successful performance of the classifier depends upon the general level of signals originating from other sources in that specific time span.

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The Multidisciplinary INGV-OE Database: Framework Architecture

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Sensor networks continuously collect a huge and heterogeneous amount of data (in the form of time series and spatial data), that needs to be properly organized in order to be used in volcano research and monitoring. The storage size of each data collection varies depending on the chosen sampling frequency and spatial resolution.

We propose a framework, hereinafter called TSSDSystem (Time Series and Spatial Database System), in order to acquire time series and spatial data from different data sources and standardize them within a relational database. In the time domain, standardization provides the ability to perform operations, such as query and visualization, of many measures synchronizing them by using a common time scale. Whereas, in the spatial domain, data are collected considering a common GIS (Geographic Information System) for data sharing and visualization.

The proposed architecture follows a multiple layer paradigm (Loaders layer, Database layer and Business Logic layer). In particular, the Loaders layer (constituted by loaders software) is specialized in reading data coming from different sources such as ASCII, Excel, ODBC (Open DataBase Connectivity), file accessible from the Internet (web pages, XML), and in its reorganization and archiving into the relational database, using a common structure. Each data source refers to a particular geospatial location and to one or multiple stations, whose information are stored in a dedicated database. The framework implements an heartbeat system, in order to check loaders working status and automate the discovery of acquisition issues and other warning conditions. To manage huge amounts of data, we perform a smart partitioning table strategy, that keeps balanced the percentage of data stored in each database table. Business Logic layer contains modules for the visualization of acquired data (both temporal and spatial), including authoring tools for multimedia contents creation and delivery. It also provides the possibility to query on a specified time range, or to follow the realtime signal acquisition, according to a data access policy for the users.

The Multidisciplinary INGV-OE Database: Tools for Monitoring and Research

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The most promising approach to detect and investigate the volcanic unrest phases and forecast the eruptions is the joint monitoring of volcanological, geophysical and geochemical data. In the last years, it has been clearly shown how the multiparametric approach is the winning strategy not only for monitoring but also for research purposes. In particular, such a kind of approach is considered the most effective to investigate the complex dynamics of the volcanic systems.

However, the systematic application of such an approach is not a trivial task. Indeed, because of the increment in the number of sensors installed on the active volcanoes and often even in their sampling rate, the amount of data continuously flowing into the observatories is dramatically increasing. Moreover, the variables collected by the different sensor networks constitute heterogeneous data sources. Another crucial task, required by an observatory, is the quick representation of spatial data, that needs a high performance Geographic Information System (GIS).

In order to face all these problems, we have developed a framework (hereinafter called TSSDSystem: Time Series and Spatial Database System), which today represents the database of INGV - Osservatorio Etneo. Such a framework allows to acquire data streams from different permanent sensor networks, located on Mt. Etna and Stromboli, and standardize them within a relational database. Also, spatial data related to different dataset are acquired using a GIS for sharing and visualization purpose. The details of the proposed architecture can be found in the twin abstract "The multidisciplinary INGV-OE database: framework architecture".

By means of such a paradigm, the following features/services are now available:

- Multiparametric stations management;
- Multiparametric time series data synchronization;
- Real-time and near real-time data visualization;
- Advanced query using web service (SOAP protocol);
- Data visualization export using common web image format;
- Geospatial data retrieving using WMS, WFS and WCS;
- Authoring tools for multimedia contents creation and delivery.

Precursory Phenomena of Volcanic Eruptions

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Hot Earth is a pioneering project that involves the systematic study of geothermal energy sources in Eastern Sicily. One of the aim is to verify on the existence of both geochemical and physical phenomena recognized in some areas, which show high geothermal potentiality, which could be also considered as precursor of volcanic eruptions.

For this reasons several multisensorial platforms (Fig.1a) were installed on Mt Etna and on the northern edge of the Peloritani Mountains, with the aim to monitoring temperature and concentration of CO_2, H_2S and Radon gas.

The sensors were located at various levels inside wells 50 meters deep from the surface, with the aim to identify the level which is considered to be the one below which, the temperature is not influenced by surface meteorological variations.

The reference site chosen for this project is the one of Salinelle, in the village of Paternò (located west of the town of Catania), known for the multiple eruptive manifestations which historically occurred. Volcanic activities of paroxysmal emission of fluids and mud were observed in 1866 [Silvestri, 1866] in 1878 [Silvestri, 1878; 1879; 1880], in 1953 [Cumin, 1954], 1983 in 2008 and 2013 (Patanè G. personal observations).

The monitoring has mainly focused on the concentrations of the bubbling gases such as the CO_2 ones, which has reached almost 100%; this gas is considered to be of magmatic origin. H_2S concentrations and temperature variations have been also monitored in order to make considerations. Some of them are listed below.

The temporal variations of CO_2 show a relationship with the summit eruptive activity of Etna volcano: lava fountains, lava flows and Strombolian activity. This latter occurred in the first days of October, 2013 (Strombolian activity of New South East Crater - i.e. NSEC) in which an increasing in the CO_2 concentration has been recorded (at the Salinelle of Paternò).

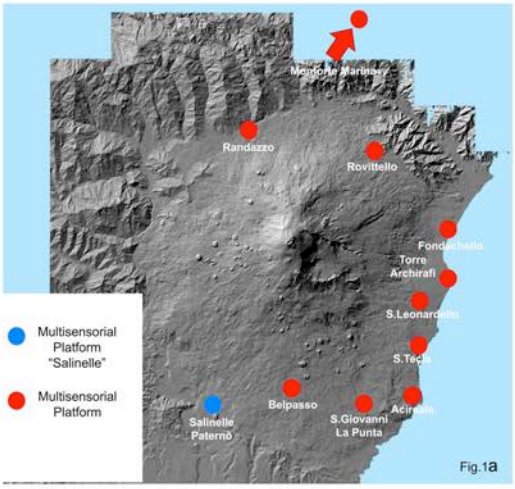
Subsequently, the CO_2 concentration decreases to average values generally very low. (Fig.1b).

Strong eruptive phenomena (fountains and lava flows) begins on Mount Etna in the end of October and in the early days of November 2013. This volcanic activity ended on March 20, 2014 on 6 May 2014 (Fig.1b).

A similar trend in the variations of CO_2 concentrations was observed before the onset of eruptive phenomena at the summit craters of Mount Etna.

In particular, in the last two years, it was observed that the average increase in the CO_2 concentration occurs in an interval from 3 to 8 months before the start of eruptive phenomena with high energy (Fig.1b).

The variation in the concentration of H_2S shows a similar trend (Fig.1c). The increase in the temperature inside the well (from a minimum of 12°C to a maximum of 45°C; Fig.1d), is clearly related to the migration toward the surface of hot magma gases in the period from July 2013 to January 2014, four months before and during the eruptive phenomena with higher energy .



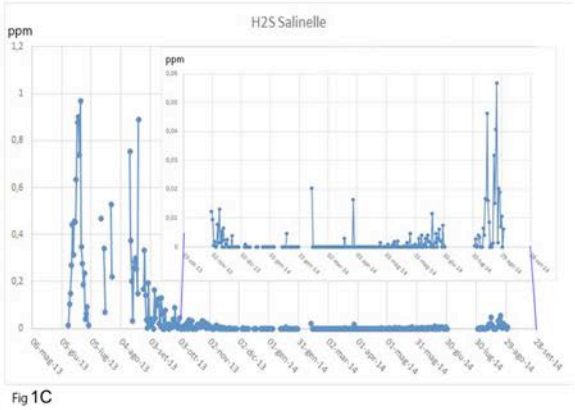


Fig 1C

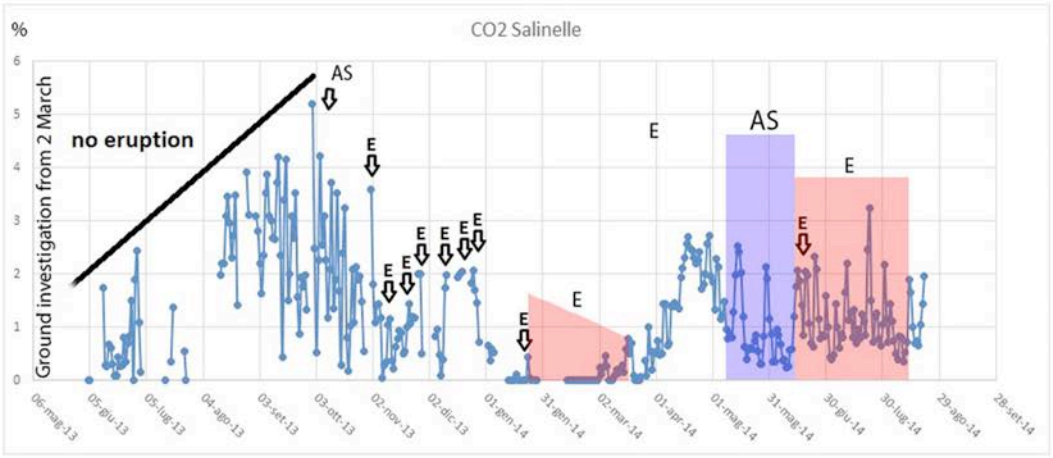


Fig. 1b

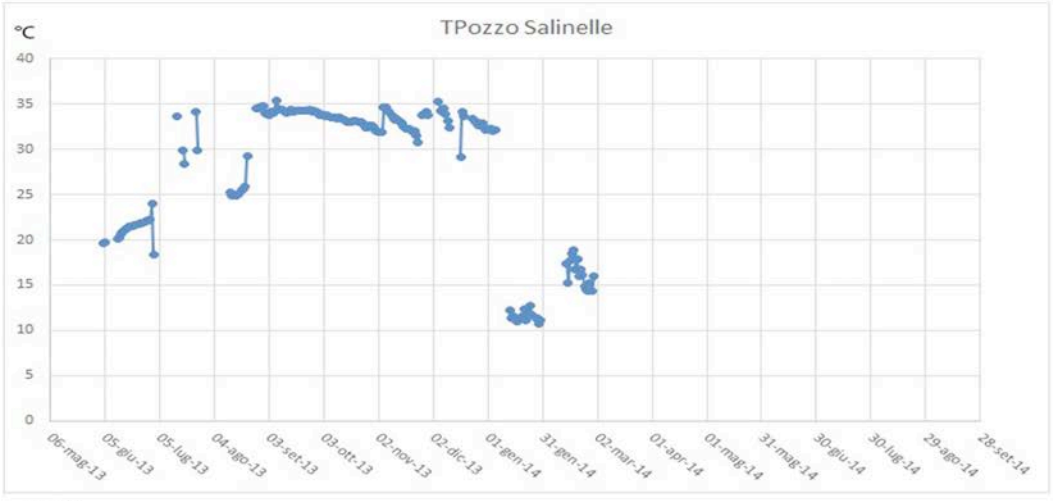


Fig 1d

Figure 1. a) Multisensorial platforms; b) CO_2 Concentration AS: Strombolian Activity, E: Strombolian and fountain lava activity, lava flow; c) H_2S Concentration; d) Average daily temperatures in geognostic well.

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Carbon Dioxide Measurements in Volcanic Atmosphere: Comparison between different Methodologies and Implications for Monitoring Purposes

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The analysis and interpretation of volcanic gas datasets offer key information to validate geological models relevant to volcanic processes, including eruptions. Moreover gas monitoring add information for the interpretation of dynamics of fluid circulation at dormant volcanoes.

We present carbon dioxide measurements carried out in two degassing systems: Campi Flegrei active caldera (2012-2013) and Paternò mud volcano at the periphery of Mt Etna (2014), suggesting that the cumulative CO_2 contribution from weakly degassing volcanoes in hydrothermal stage of activity may be significant at global scale.

In detail, we report on the first ever obtained gas output estimates from Campi Flegrei fumaroles near Pozzuoli by performing a set of Tunable Diode Laser and MultiGAS observations with an ad-hoc designed measurement set-up [Pedone et al., 2014; Aiuppa et al., 2013].

We also introduce the first measurements of gas output from several bubbling mud pools in a mud volcano located in Paternò area, in the southern flank of Etna, by using Tunable Diode Laser, MultiGAS and a home-made apparatus, able to capture all the bubbles over an area of 0.4 m² [Federico et al., 2014].

Tunable Diode Laser Spectroscopy (using the Infra-Red GasFinder 2.0), which relies on measuring the absorbance at specific wavelengths due to the absorption of Infra-Red radiation by a target gas, was performed in each site to contour the carbon dioxide distribution in their atmospheric plumes and to quantify the volcanic CO_2 emissions. The results from Tunable Diode Laser Spectroscopy are comparable with the other techniques performed. In particular, deriving the two-dimensional contour maps of CO2 mixing ratios, the higher CO_2 values were detected near the most vigorous degassing vents/bubbles and the lower, as expected, were observed up-wind and at plume margins.

Based on the mixing ratios contours, CO_2 output was estimated for Campi Flegrei area (a GoPro-camera was used here to calculate the vertical transport speed from fumaroles).

At Campi Flegrei, they both techniques suggest that the fumarolic CO_2 output is, surprisingly high (about 490 tons/day by using GasFinder and about 460 tons/day by using MultiGAS), at least for a dormant volcano in hydrothermal stage of activity.

For Paternò area, the further elaboration of the flux rate (from post-processing the GasFinder datasets) requires accurate measurements of the vertical upward air convection, planned in the future. At moment, a preliminary estimate of the total CO_2 output over the whole mud volcano, from the home-made apparatus, is about 1 tons/day.

The application of lasers to volcanic gas studies and the periodic survey of total CO_2 output in a subset of vigorously degassing vents/pools, routinely performed, would offer a robust monitoring tool in volcanic areas.

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2011-2013 Campi Flegrei Unrest Process Detected and Modeled by SAR Interferometry

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Campi Flegrei caldera is a volcanic district located west of Naples, included in the list of GEO Supersites and characterized by one of the highest volcanic risk worldwide. The persistent volcanic activity produces a peculiar phenomenon known as "bradyseism" leading to spectacular ground level variations across the centuries, even of the order of meters.

In the present work InSAR (Interferometric SAR) technique has been applied to investigate the significant volcanic unrest process occurred between 2011 and 2013 at Campi Flegrei caldera.

Two dataset of Cosmo-SkyMed SAR images acquired along both ascending and descending orbit have been used.

The ascending orbit dataset consists of 168 SAR images spanning from January 2011 to September 2013 whereas the descending orbit covers from February 2011 to December 2013. This latter is characterized by a sparser temporal sampling being composed by 46 SAR images.

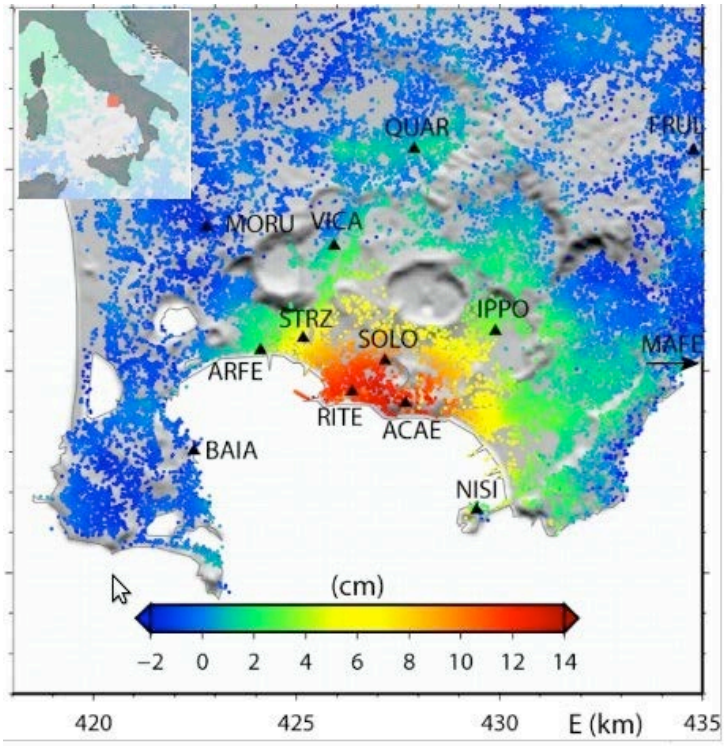

Figure 1. Line of Sight displacement estimated along descending orbit.

Experimental results show a semicircular deformation pattern centered close to the Rione Terra (Pozzuoli) and characterized by an uplift rate peaking around to 4.5 cm/y, decreasing towards the neighboring areas of Arco Felice and Capo Miseno (west), Pianura and Quarto (north) and Bagnoli and Naples (east).

Some GPS data belonging to the Neapolitan Volcanoes Continuous GPS (NeVoCGPS) network for monitoring the Campi Flegrei activity have been exploited in order to compare and validate the results provided by SAR analysis.

The comparison between GPS and SAR shows a good agreement when projecting the GPS East North_Up vectors along the satellite geometry (Line of Sight). We found a good agreement between the vertical displacement components, whereas the horizontal components show worse results due to high incidence angle (23° average) and the resulting lower accuracy of SAR measurements.

The GPS and SAR deformation data have been modeled by adopting the Finite Element technique in order to constrain the source characteristics. The sill-like source, embedded in a 3D heterogeneous medium, is found to be located offshore Pozzuoli at about 5 km depth.

Proposal for a Conceptual Model behind possible Scenarios for Mt. Etna Flank Dynamics

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Mt. Etna flank dynamics poses a serious hazard, also involving the inhabited lower slopes.

Considering the significant amount of data collected on the dynamics of its eastern and southern flanks, we propose a conceptual model to describe and explain flank dynamics at Etna, identifying the preconditions, as due to the differential unbuttressing conditions at the volcano base, and shallow magmatic sources (dikes, reservoirs).

Based on this, we then propose a set of scenarios possibly occurring in case of unrest of the unstable flanks of Mt. Etna. Flank unrest is a variation in the steady state condition of the volcano flanks, possibly accompanied by significant ground deformation, seismicity and eruptions. The scenarios may provide a general reference and recommendation in case of five types of multi-hazard processes related (either as a cause or effect) to flank dynamics:

1) edifice inflation;
2) emplacement of dikes along the NE and/or S rifts;
3) seismicity along Pernicana Fault System;
4) seismicity on the S sector;
5) seismicity along Timpe Fault System.

The scenarios may or may not be related to each other, in the sense that the probability of occurrence of one scenario may or may not be contingent or dependent upon the prior occurrence of another. Each scenario is analyzed and recommendations are given. These scenarios provide a qualitative analysis of the multi-hazard processes related to flank dynamics and might be assumed the base for implementing a more quantitative (i.e. probabilistic) characterization of the threatening events.

Estimates of Complete Moment Tensor of Seismicity Occurred at Mt. Etna in the Period 2005-2013

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It is very well known [i.e. Saraò et al., 2010 and reference therein] that the analysis of moment tensor in volcanic environment is a quite delicate issue, due to the complexities of the structural model, to the wave propagation effects as well as to the presence of noise. For the seismicity of Etna area, due to the complex interaction between tectonic stress and volcanic dynamics, a complete moment tensor analysis accounting also for non-double couple components is necessary for a comprehensive study of the source. The earthquake source in volcanic environments is well studied through the seismic moment tensor decomposed into double-couple (DC) and non-double couple components that are represented by the compensated linear vector dipole (CLVD) and the volumetric (ISO) part. If the DC component is linked to shear dislocations, the CLVD part can be due to lenticular crack activation accompanied by possible fluid motion whilst the ISO component represents volume changes due to implosion or explosion. However non-double couple solutions can be found also as artifacts of the inversion process, therefore well-tested methods and feasibility tests are preparatory to each analysis in such environments in order to guarantee reliable solutions.

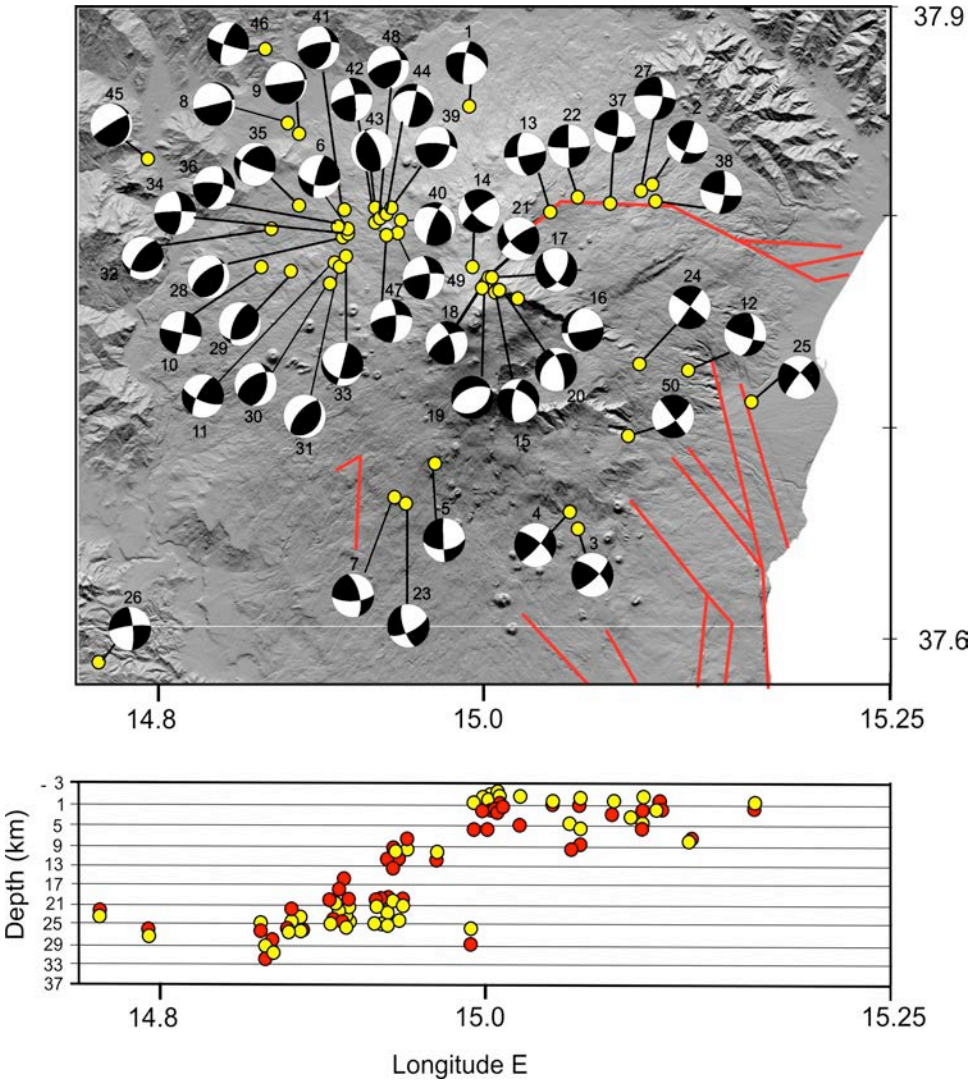

Figure 1. Epicentral map of the INGV-OE selected earthquakes (yellow circles) and focal mechanisms obtained by the moment tensor. In the bottom panel, W-E cross section with the INGV-OE hypocenters compared with that computed by moment tensor (red circles).

In this study we computed the moment tensor of the most energetic earthquakes (M_L between 3.4 and 4.8) occurred at Etna volcano in the period 2005-2013 and recorded by the broad-band network of Osservatorio Etneo. The aim was either to calculate robust focal mechanisms, or to have an independent estimate of the moment magnitude (Mw) but also to analyze the sources of non-double couple as possibly connected with the tectonic or volcanic dynamics of the volcano.

After a careful selection of data quality, we set up a dataset of 50 events. For each event three-component seismograms have been inverted using the algorithm developed by Minson & Dreger [2008] in the frequency range 0.02-0.10 Hz.

Several tests were performed to check for the influence of the different velocity models available for the area. We finally used an average 1D velocity model extracted from the 3D one of Patanè et al. [2006] whilst the input density model and the attenuation factor (Q) were defined as in Saraò et al. [2010].

The focal mechanisms obtained (Fig. 1) have been compared with independent estimates of fault plane solutions computed by first polarities analysis [i.e. Scarfì et al., 2013] and an excellent agreement was found. Interesting results have been obtained for the Provenzana - Pernicana seismicity showing high non-double couple components, which may be probably due to fluids circulation observed by geophysical and geochemical measurements [Siniscalchi et al., 2010]. High double couple percentages in the deep earthquakes (up to 30 km b.s.l.) may be due to the activation of the regional tectonic structures related to the Apenninic-Maghrebian Chain compressive regime [Alparone et al., 2010]. The high DCs of the events belonging to the seismic swarm accompanying the 2008 eruption might be related with the formation of the dry eruptive field during that eruption [Aloisi et al., 2009].

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The "Bridge" Network of Permanent SO_2 Cameras: First SO_2 Flux Results from Etna and Stromboli

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The SO_2 camera is becoming an important new tool in the armory of volcano monitoring to derive high time resolution SO_2 flux measurements. The high spatial resolution of the camera is particularly useful for near-vent SO_2 flux measurements and therefore for exploring those poorly studied plume features that are lost during transport in the atmosphere. Here, we present the first results of ERC-FP7 project "Bridge", one of the primary aims of which is the installation of an automatic network for high-rate SO_2 flux measurements at Stromboli and Etna. Data from the network will be used for characterizing degassing processes at high temporal resolution, and for inter-comparing gas data with contemporaneous geophysical signals - therefore establishing a link (bridge) between geochemistry and geophysics. A novel type of miniaturized SO_2 cameras is coupled with a differential optical absorption (Mini-DOAS) spectrometer to derive more accurate measurements of volcanic gas emissions. Two SO_2 camera stations have been installed on Stromboli at 0.5 km (Roccette) and 1.75 km (Sciara del Fuoco rim) from the crater terrace. Further, two similar stations have been deployed on mount Etna at 2.3 km (Pizzi Deneri) and 3.6 km (Montagnola) from the summit craters in order to image the plume from different angles and directions. Data acquisition started at the beginning of June 2014, recording intense eruptive activities of both Stromboli and Etna. This growing dataset is stored on a Network Attached Storage and processed with a specifically projected software (Vulcamera). This code is made user-friendly to enable volcanologists, who are not experts in the underlying physics of spectroscopy and image processing, to perform complex calculations in a fast way. The program provides considerable reduction in errors and far greater operating flexibility. As a typical example, the installation at Stromboli volcano (Roccette) is described, together with some results from the first months of operation at this volcano, covering the recent Stromboli's unrest.

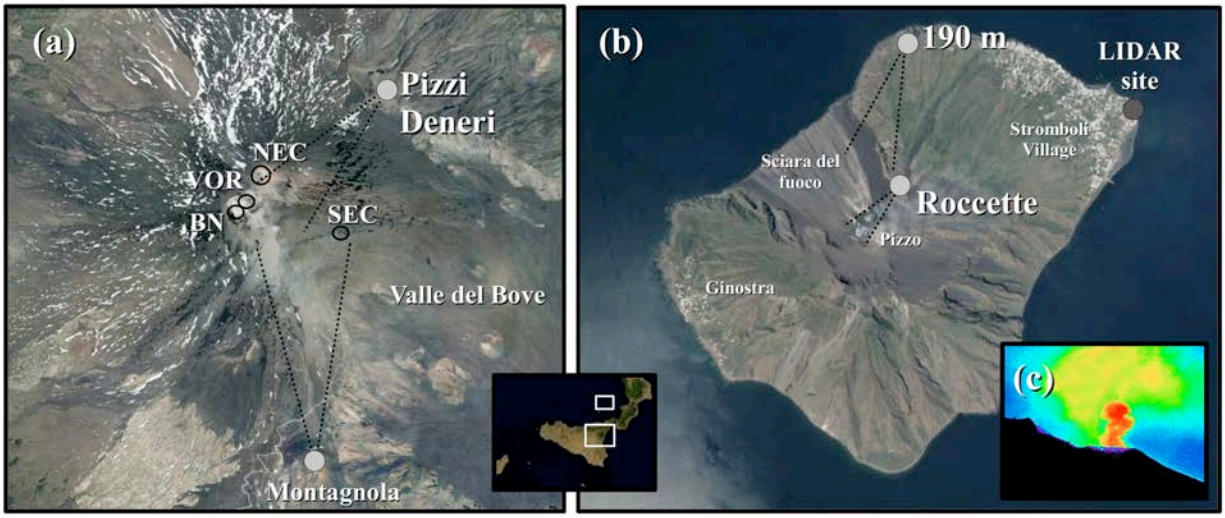

Figure 1. A schematic map of the SO_2 camera arrays realized at both Etna (a) and Stromboli (b) during June 2014. (c) SO_2 absorption image captured from the rim of Sciara del Fuoco's (190 m a.s.l.).

Spectral Characteristics of Sea Level Gauges for Ground Deformation Monitoring at Neapolitan Active Volcanoes: Somma-Vesuvius, Campi Flegrei caldera and Ischia island

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Actually the tide gauge network at Neapolitan volcanic area consists of nine stations: seven in Gulfs of Naples and Pozzuoli, one at Ischia island and one in Gulf of Salerno. The data analysis of the sea level time variations is performed by referring the data measured at tide-stations to the data collected at Naples (Reference Station). Data have been analyzed in the frequency domain and the local astronomical components have been defined by harmonic analysis, inferring amplitude and phase for the main diurnal and semi-diurnal components. The obtained residual respect to the astronomical tide contains information about meteorological component, eustatic variation, ground deformation and noise. The residual sea level variations, for each site, can be represented by two terms: sea level background and local sea level variations due to noise, site effects and ground deformation. Removing, by deconvolution, the differential behaviour of the sea-level respect to a reference station, provide an estimation of the ground level variation [Obrizzo et al., 2009, Capuano et al., 2012]. The results show that, in the Campi Flegrei caldera, tide gauge data have been able to detect the so-called mini-uplift episodes occurred in the last years and no significant level variation at Vesuvius. The reconstruction of vertical movements by means tide gauge is well correlate with the deformation seen by classical optical leveling and GPS [De Martino et al., 2014; Tammaro et al., 2013]. The tide gauges also recorded a spectrum of tides and harmonic resonances of the sea surface, called seiches, in the Bay of Naples and Pozzuoli [Capuano et al., 2004b]. Spectral analysis shows the typical frequency excited in the Gulf of Naples (about 20, 30 min., consistent with seiches phenomenon) and the Tyrrhenian sea eigenperiod (about 60 min., see [Speich and Mosetti, 1988]). In particular, four tidal species are identified: diurnal, semidiurnal, 3 cycles/day and 6 cycles/day. They decay slightly in coherence with decreasing period. Coherent sea level variations occur at nine dominant periods for seiches between 3 hours and 0.7 hours. For periods less than 40 minutes the spectral energy density varies significantly between the three gauges of Miseno, Pozzuoli and Nisida, probably due to short wavelength resonances near harbours. Moreover tide gauge data recorded in the Gulf of Naples and in the Bay of Pozzuoli show some variations caused by the anomalous wave such as that (with period of about 70 min) produced by a submarine landslide occurred on December 30, 2002 at Stromboli volcano [Capuano et al, 2004a].

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Seismic Hazard Mapping inside the Project SIGMA

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The Project SIGMA (Sistema Integrato di sensori in ambiente cloud per la Gestione Multirischio Avanzata) arises from the fields of Information and Communications Technologies (ICT) and advanced applications for the control, monitoring and management of high-risk processes of natural and social origin. SIGMA is a multilevel architecture whose main aim is the acquisition, integration and processing of heterogeneous data from different sources (seismic, volcanic, meteorologic, hydric, pluvial, car traffic, marine traffic, and so on) to manage and elaborate risk mitigation strategies which are important for the emergency management planning. Within the several experimental activities included in the project, there is the designing and realization of a prototype of application platform specialized to provide the operating procedures and software to the public administrations and the industrial companies, for constantly monitoring both the anthropic and natural phenomena in Sicily. In this framework, of course, the seismic risk analysis plays a very important role since Sicily is one of the Italian regions with high seismic risk.

Seismic risk assessment may be approached in two different ways: i) as average seismic risk of the buildings and facilities in question during the period considered, combining the vulnerability of different building types and the seismic hazard for the site, which are then expressed in terms of the effects of the events derived from an earthquake catalogue that exceed a specified threshold during a given period; ii) as estimated damage of the buildings and the critical facilities using a scenario input described in terms of the source parameters of the hypocenter as location, magnitude, and so on.

Here we deal with the hazard calculation through the code CRISIS (Ordaz, Aguilar and Arboleda) and with the code PROSCEN (PRObabilistic SCENario, [Rotondi and Zonno, 2010]) to obtain earthquake scenario to be used in the latter approach. Indeed, an earthquake scenario is a planning tool that helps decision makers to visualize the specific impact of an earthquake based on the scientific knowledge. An earthquake scenario creates a picture that the members of community can recognize and, at the same time, improves the communication between the scientific, emergency management and policy communities to seismic risk reduction.

In particular, CRISIS computes seismic hazard using a probabilistic approach that consider as input parameters the earthquake occurrence probabilities, attenuation characteristics and geographical distribution of earthquakes in the studied area. The hazard results are given in terms of probabilities of exceeding a given peak ground motion in different time frames. More in detail, the area under study is first divided into seismic sources; then, within a seismic source an independent earthquake-occurrence process takes place. Thus, for each seismic source, earthquake occurrence probabilities are estimated by means of statistical analysis of earthquake catalogs. Conversely, PROSCEN estimates the seismic scenarios by adopting a probabilistic approach based on the Bayesian statistics [Rotondi and Zonno, 2004] and modelling the attenuation of the macroseismic intensity both in the case of point source (isotropic model) and linear source (anisotropic model). The code needs just two input parameters to generate the earthquake scenario, that is the location and the epicentral intensity (together with the fault geometry for the anisotropic model) of the given earthquake. The scenario results are plotted on grid maps representing the intensity that can be exceeded with a fixed probability. This representation can easily find application in seismic monitoring of an area, since can be used to produce real-time shake-maps in intensity based on the earthquake parameters calculated automatically from the instrumental recording and location routines.

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Chemical and Isotopic Composition of Thermal Waters and Dissolved Gases from Campi Flegrei (southern Italy): Insights into Isotopic Fractionation Processes Affecting the CO_2 Isotopic Signature

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In the framework of a study aimed to investigate the interactions between superficial aquifers and uprising deep-originated hydrothermal fluids at the Campi Flegrei volcanic district (southern Italy), water and dissolved gases from wells, springs and Lake Averno for chemical and isotopic (delta13C in CO_2) analyses were recently sampled and analyzed. This area is characterized by an intense hydrothermal activity that at the surface originates hot springs, steam-heated pools, sub-aerial fumaroles, mostly located within two craters (Solfatara and Agnano), along with a number of submarine vents in the Pozzuoli Bay.

The hydrothermal circulation pattern is likely fed by: (i) a Na-Cl deep brine with high salinity and T and rich in CO_2, whose isotopic signature is relatively heavy (- 1 ÷ -2 ‰ vs. V-PDB); (ii) a HCO_3-rich component, also displaying high salinity and T; (ii) meteoric water; (iv) seawater, mostly in the coastal area. N_2-rich dissolved gases, with relatively high O_2 and Ar contents, are commonly associated with cold water wells characterized by relatively low CO_2contents (<10 % by vol.), likely deriving from microbial activity, as suggested by the delta13C- CO_2 values, which range from -23.7 to -19.7 ‰ vs. V-PDB. Thermal waters show significant enrichments in dissolved CO_2 (24.1 to 89.8 % by vol.), whose origin is likely associated with the deep source, as the delta^{13}C- CO_2 values are from -7.56 to -5.03 ‰ vs. V-PDB.

This study has individuated the occurrence of a third group of waters characterized by relatively high concentrations of CO_2 (21 to 90% by vol.) with delta^{13}C values in between the other two types of waters: -15.2 and -11.8 ‰ vs. V-PDB. These waters (Lake Averno, Stufe di Nerone, Esposito and Damiani wells) are all located in a narrow zone close to Monte Nuovo, where the latest historical eruption at Campi Flegrei occurred (1538). By combining the CO_2 concentrations and delta^{13}C- CO_2 values, a simple mixing process between deep and shallow end-members is not able to reproduce such intermediate isotopic signatures, rarely recognized in fluids from volcanic and geothermal areas.

Therefore, the carbon isotopic composition of these waters should reflect a different deep source or, more likely, secondary fractionation processes altering the original isotopic signature of the deep CO_2. This process would be favored by chemical-physical conditions prevailing in a very restricted area. Calcite precipitation can cause an isotopic fractionation able to modify the original magmatic delta^{13}C- CO_2 values into those measured in the four anomalous samples. This process seems to be efficient only for those fluids collected in the area of Monte Nuovo, which prior the 1538 eruption was covered by the sea. Occurrence of a seawater-like aquifer at shallow depth is also suggested by the chemistry of the Stufe di Nerone and Lake Averno waters.

It is worth noting that anomalous delta^{13}C- CO_2 values were also recognized in the fluid discharges inside and close to the village of Sake, which is located in the southernmost part of Nyamulagira volcano (DRC), as well as at the bottom of the adjacent Kabuno Bay (-11.48 ‰ V-PDB) that is the north-westernmost extension of Lake Kivu. These isotopic values are in contrast with the typical magmatic isotopic signature characterizing the fluid emergences of the whole area and are not in agreement with that measured at the bottom of Lake Kivu Main basin (-6.79 ‰ V-PDB). In analogy with what observed at Campi Flegrei, it is realistic to suppose that the deep-originated fluids discharging in the Sake area can be affected by secondary process, induced by local and peculiar chemical-physical conditions, able to cause such a dramatic isotopic fractionation of CO_2. Further studies are needed to deeply investigate on this uncommon geochemical feature.

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