

# *EUG XI*



Symposium VPP6

Volcanic Hazards: Monitoring,  
Prediction and Mitigation

Convenor

Hazel Rymer

## Sunday PO Session

## VPP6 : SUpo01 : PO

Volcanic CO<sub>2</sub> Fluxes from the Lofos Dome Area, Nisyros (Greece)

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Nisyros island is the emerged portion of an andesitic volcano belonging to the Aegean active volcanic arc. The western part of the summit caldera is characterised by the presence of a series of dacitic-rhyodacitic domes. The youngest one, Lofos dome, is affected by an intense fumarolic activity, fed by an active high-temperature hydrothermal system, and its summit is surrounded by several hydrothermal craters. During May and September 2000 we carried out two CO<sub>2</sub> soil diffuse flux and soil temperature measurement campaigns in order to investigate the structures releasing the gas and to compute the total CO<sub>2</sub> output of the Lofos area. A total of 1268 CO<sub>2</sub> flux measurement have been performed using the accumulation chamber method, according to a 20 m regularly spaced grid. The spatial distribution of CO<sub>2</sub> fluxes shows that most of the anomalous areas are aligned along a SW-NE direction except for a SE-NW elongated anomaly in the northern sector of studied areas. The main SW-NE anomaly in the southern sector roughly coincides with the hydrothermal craters. The correspondence between areas of high soil temperature and high  $\phi$ CO<sub>2</sub> suggest that hot hydrothermal fluids ascend from the underlying boiling hydrothermal reservoir towards the surface and that steam condensation in the subsoil is responsible for the high  $\phi$ CO<sub>2</sub> and the elevated soil temperature. Statistical analysis of flux values allowed to distinguish the background CO<sub>2</sub> flux from the flux connected to the uprising of hydrothermal fluids. The total CO<sub>2</sub> output, based on the results of the two campaigns, is about 28td<sup>1</sup>, of which 42% is represented by the hydrothermal component. This large quantity of gas is of the same order of magnitude of the CO<sub>2</sub> released from the nearby Stefanos crater (Brombach et al., 2000) that is located south-east respect to the studied area. As pointed out by Brombach et al. (2000) the diffuse hydrothermal CO<sub>2</sub> degassing process is associated with a thermal energy flux that can represent a significant figure in the energy budget of the volcano.

Brombach T, Hunziker JC, Chiodini C, Cardellini C & Marini L, *Journal of Geophysical Research Letters*, in press, (2000).

## VPP6 : SUpo02 : PO

## A New Index for Evaluating the Gas Injection into the Stratosphere Caused by Explosive Volcanic Eruptions: VGIS (Volcanic Gas Input into the Stratosphere)

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Volcanic gases such as SO<sub>2</sub>, H<sub>2</sub>S, HCl, COS emitted during explosive eruptions have a significant effect on the atmospheric chemistry and therefore on Earth's climate. In order to quantify the flux of volcanic gases into the stratosphere we have developed a new index VGIS (Volcanic gas input into the stratosphere) based on the VEI (Volcanic explosivity index), altitude and latitude of a volcano, tectonic setting and the amount of gas emission by explosive eruptions. Tropic eruptions have to be much more powerful to inject gas into the stratosphere than eruption plumes at high latitudes because the tropopause rises from ca. 7 km (winter) at the poles to 17 km (summer) in the equatorial area (0° - 30° N and S). Woods (1988) has shown that the altitude at which an eruption occurs influences not significantly the total height of a volcanic plume, despite a decrease in atmospheric pressure with increasing altitude. Thus, we assumed the total heights for plumes of a certain VEI (same eruption rate) to be similar. It is the distance between the top of a volcano and the tropopause that is the significant parameter for assessing the potential stratospheric gas input of a volcanic eruption, and this can be expressed by its VGIS. We correlated the latitude and altitude of 360 active volcanoes with the height of the tropopause at that latitude interval for calculating the amount of volcanic gases potentially injected into the stratosphere. Detailed monitoring of gas emissions since the early 70's has shown that the gas output differs significantly between volcanoes even within the same tectonic setting. Disregarding such variable gas flux rates, the new index allows to assess the difference between equatorial eruptions (0° - 30° N and S) with a low VEI (<4) that can not inject gas into the stratosphere and volcanic eruptions at high latitude. Despite the uncertainties mentioned, we think the VGIS index will give a first approximation of the amount of gas (e.g. SO<sub>2</sub>) that will reach the stratosphere after an explosive eruption. This index is especially useful for gas estimates of historic eruptions.

Woods AW, *Volcanology*, 50, 169-193, (1988).

## VPP6 : SUpo03 : PO

## Geochemical Surveillance of Fluid and Gas Discharges at Yasur Volcanic Complex, Tanna Island, Vanuatu

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Located on Tanna Island in the southern Vanuatu archipelago, the Yasur Volcanic Complex (YVC) is one of the most active volcanic structure of the New Hebrides arc. Among its main features, the YVC comprises the recent (<10,000 years) Siwi caldera which accommodates a tectonically active horst, the Yankaha resurgent dome, and the active Yasur cinder cone at the western end of the horst. Yasur volcanic activity consists of persistent degassing associated with strombolian- to vulcanian-type explosions producing slightly differentiated andesites. An extensive hydrothermal system developed within the YVC and is characterized by the occurrence of warm pools, hot springs and close-to-boiling-point fumaroles on and around the Yankaha dome. During a field survey in 1999, we combined remote sensing of the volcanic plume (COSPEC and FTIR measurements) and in situ sampling of thermal waters and fumaroles, with the aim to constrain degassing processes at the YVC. The average daily output of SO<sub>2</sub> was measured by COSPEC at about 500 t/d, which makes Yasur a standard gas-emitter among arc volcanoes. Assuming an initial sulfur content of about 400 ppm for a deep undegassed andesitic magma (Wallace and Anderson, 2000), the measured SO<sub>2</sub> flux is explained by a daily input of degassing magma of 200,000 m<sup>3</sup>/d. Visual observations show that the lava production at the surface is probably no more than 200 m<sup>3</sup>/d, suggesting that most of the degassed magma is unerupted and must be stored at depth, potentially beneath the Yankaha dome. FTIR data show the lack of HF in the plume and yield unusually low Cl/S mass ratios of only 0.03, which might be explained by F- and Cl-bearing aerosols scavenging due to rainy weather conditions. Thermal waters, mostly neutral to alkali in pH and Na-K-Cl-rich, have temperatures ranging from ambient up to 99°C. Chemical compositions suggest that these waters result from a complex mixing between a geothermal fluid, that might be recycled and altered seawater, and both local meteoric water and seawater. Deuterium and oxygen isotopes support this hypothesis and show a slight positive shift in <sup>18</sup>O indicating isotopic exchange with hot rocks. Geothermometers based on water cation contents indicate that these waters are partly to totally equilibrated and yield an equilibrium temperature of 200-250°C for the geothermal reservoir. Fumarole gases are typical of volcanic-hosted hydrothermal systems with comparatively high CO<sub>2</sub> and H<sub>2</sub>S contents. Their chemistry is dominated by air-saturated meteoric water but contribution of both mantle and slab components can be identified in a N<sub>2</sub>-He-Ar ternary plot. Use of the CO<sub>2</sub>-CH<sub>4</sub> geothermometer indicates an equilibrium temperature of 240°C for the geothermal reservoir. All these results support the hypothesis of hot magma beneath the Yankaha dome that degasses magmatic fluids and reheats seawater infiltrated in the YVC.

Wallace P & Anderson AT, *Encyclopedia of Volcanoes*, Ed. Sigurdson H.; Academic Press, 149-170, (2000).

## VPP6 : SUpo04 : PO

## Ground Deformation Monitoring of Volcanic Areas in Sicily (Italy)

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The mitigation of volcanic hazard in Sicily is under the responsibility of Sistema Poseidon. This activity is carried out using monitoring networks located on the volcanoes Etna, Stromboli, Vulcano and Pantelleria. At present geodetic monitoring consists of both regular surveys (with the exception of Stromboli volcano) and continuous monitoring. The surveys have been carried out since 1975 using EDM (Electrooptical Distance Measurement) and more recently using the GPS (Global Positioning System) technique, which has several advantages over EDM. Continuous ground deformation monitoring is carried out using different methodologies: GPS provides near real-time knowledge of the deformation parameters (variations of distances and quotas, strain parameters) which are of interest as precursors to volcanic eruptions. Tilt monitoring is carried out through biaxial bore-hole tiltmeters installed at depths between 2.5 and 10 meters. These instruments are able to measure tilt variations as small as 0.01-0.1 microradians. Data are delivered from the remote station to the recording center every 30 minutes and each tiltmeter is oriented so that one of the axes, called the radial component, points toward the volcano summit area. Strainmeters are arranged in small networks located on Mt. Etna, in areas which have a key role in the dynamics of both volcanic and seismic processes.

We summarize the main results obtained in the last few years from studies of ground deformation signals and from other monitoring techniques. In particular we describe the recent evolution of Mt. Etna's activity and some hypotheses about the injection processes of magma; volcanology of the Lipari-Vulcano area within the geodynamical framework; and hypothesized deformation sources for Stromboli and Pantelleria volcanoes.

## VPP6 : SUpo05 : PO

## Numerical Modelling of Ground Deformation Revealed at Mount Etna by ERS

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Previous works have proposed that the dynamic of Mount Etna is dominated by large scale flank instability. An analysis of 238 interferograms calculated from 38 ascending ERS images, corresponding to 6 years of interferometric survey (from September 1992 to January 1999) reveal for the first time an active spreading on the eastern and southern flank of Etna. Two main sectors of instability, driven by different process, have been identified. An eastern sector bounded by the Pernicana faults system to the north, by the North and the South Rift Zones to the West and by the Mascalucia-Tremestieri-Trecastagni faults system (MTTFS) to the South East, slides to the east. In this sector, the spreading appears to be controlled mainly by regional EW extension. A southern sector, limited to the south by an active anticlinal ridge, is driven by southward gravity spreading over a basal decollement between the sub-Etnean clays and the Hyblean platform. The onset of the sliding coincide with a new cycle of volcanic activity in summer 1996.

The displacement field observed by radar interferometry constitute our initial data for the understanding of the superficial deformations of the south-east of Mount Etna. This displacement field is characterised by deformation rates ranging from 0.4-0.6 cm/yr for the MTTFS to 1.2 cm/yr for the anticlinal ridge.

Regional fringes related to tropospheric effects have been removed from the interferograms in order to keep only the expression of the shallow displacements.

We use numerical modelling in order to constrain the mechanics and the kinematics of spreading processes of Mount Etna. This modelling is based on the three-dimensional boundary elements methods. This method takes into account the realistic topography of the volcanic edifice. By forward and inverse problems, we define more precisely the stress field (value, dip and dip angle of principal stresses) which cause these deformations of the volcano, and the aspect of the major south-eastern faults. This work points out the interest of coupling analogic and numerical study to understand the evolution and the stability of a volcanic edifice.

#### VPP6 : SUPO06 : PO Perspectives for the Use of Multi-View, Multi-position Digital Photographic 3-D Morphology Reconstruction in Volcano Monitoring

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The use of classical stereophotogrammetry in volcano monitoring to compute 3-D morphology and deformation, has been used with some success on for deformation at Mt Saint Helens (Moore and Albee, 1981; Zlotnicki et al. 1990); for studying lava flow, or dome development (Kelfoun, 1999); and for analysing volcano-tectonic structures (van Wyk de Vries et al. 2000). Classic stereophotogrammetric techniques are based on static models composed of 2 rigidly fixed camera views, with fixed and known camera attributes. With such techniques it is difficult to measure the surface for complex circular geometries, such as cones or craters. From vertical views, steep features, such as crater walls, failure scars, or dome flanks are not well characterised. Recent advances in computer vision have demonstrated that accurate reconstructions are possible using a very short focal length lens (fish-eye) as well as a zoom lens. Results in self calibration from Bundle adjustments, also allow us to use a set of independent views taken from the same camera all around the object. The algorithm finds first all extrinsic geometry of the optical configuration (i.e. we compute the position in space (rotation and translation) of all the views). Then a correlation is made by dense matching of points to arrive at the 3-D structure. This technique has the advantage in that: (1) It can unravel very complex geometries: it can accurately 'see' horizontal and vertical detail. (2) Even a hand held camera used on a crater edge, or from an aircraft can provide the images: no special classical photogrammetric planning is required. (3) It can be used from outcrop scale (e.g. to analyse fractures) to whole volcano scale, with the same equipment. The digital cameras available give detection limits of between 1:40,000 and 1:100,000 of the field of view (so for a field of view of 1 km a precision of 1 cm is theoretically possible). With digital definition continually improving, precision could rival classical surveying techniques, with the advantage of providing a field of deformation, rather than separate points. We compare the scales of volcanic features and deformation types with actual and projected precision of the new technique to assess its potential in monitoring and hazard research. It shows best promise for (1) the surveillance of domes and lava flows, (2) for large slope instability movements and major constructional/erosional changes, (3) for analysis and monitoring of local deformation, and (4) for finer scale surface change for cones devoid of vegetation. As the technique produces visually impressive data, that can be combined with original photographs to make easily understandable images, thus it is also a valuable technique for the communication of information to public and authorities.

Kelfoun K, *PhD Thesis (LMV - Université Blaise Pascal)*, (1999).

Zlotnicki, J, Ruegg JC Bachelery P & Blum PA, *J. Volc. Geotherm. Res.*, **40**, 197-217, (1990).

Moore JG & Albee WC, *USGS. Prof. Pap.*, **1250**, 123-134, (1981).

van Wyk de Vries B, Kerle N & Petley D, *Geology*, **28**, 167-170, (2000).

#### VPP6 : SUPO07 : PO Determination of Volcanic Risk Areas in Mt Etna (Sicily) using a Statistical Method Based on Cellular Automata Simulations

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The determination of risk zones in the inhabited areas threatened by destructive phenomena such as lava flows, landslides, lahars, etc, represent only one of the innumerable problems of the sustainable development. Our first two-dimensional CA model for the simulation of lava flows, SCIARA (Smart Cellular Interactive Automata) for modeling the Rheology of Aetnean lava flows, to be read as 'shea'rah' was tested and validated with success on several lava events like the 1986/87 Etna eruption and the last phase of the 1991/93 Etna one. The comparison between the real and simulated events is satisfying within limits to forecast the surface covered by the lava flow. Moreover, improved versions have been upheld on other real lava flows of Mount Etna and of Reunion Island (Indian Ocean). The positive results transpired in the validation phase allowed us to apply the model for studying risk conditions of the towns of Nicolosi, Pedara and S. Alfio, threatened by Etna. Selecting opportune test regions and coupling statistical methods and simulations of a large number of probable events, permitted to individuate many critical conditions, whose happening involves a direct danger toward the chosen area. A second major Etnaean area was considered for determining risk areas in the Sicilian region: the Zafferana Etna area. Several simulations were carried out in this case. The most dangerous area seems to be the locality of Malopasso, more than Zafferana. At last, this study has permitted to evidence the existence of 'weak' zones where the building of appropriate defense constructions could represent a valid protection instrument.

Crisci G.M., S. Di Gregorio, F. Nicoletta, R.Rongo, W. Spataro, *Natural Hazards*, **20**, 215-229, (1999).

Crisci G.M., S. Di Gregorio, F.Nicoletta, R. Rongo and W. Spataro, *Cellular Automata: Research Towards Industry*, S. Bandini, R. Serra, F. Suggi Liverani (eds) - Springer, 106-116, (1998).

Di Gregorio S., R. Rongo, W. Spataro, G. Spezzano, D. Talia, *Future Generation Computer Systems*, **12**, 357-369, (1997).

#### VPP6 : SUPO08 : PO Geochemical Characterisation of the Fluid Phases at Kilauea Volcano, East Rift Zone (Big Island, Hawaii, USA)

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The volcanic activity at Kilauea (Big Island, Hawaii) is almost continuous at Pu'u O'o vent along the East Rift Zone (ERZ) since 1983. The relatively easy access to the summit region and the spectacular eruptions make Kilauea one of the most investigated volcanoes in the world, although complete gas chemical analyses are missing. Fumarolic gases, condensates and coastal thermal springs were sampled along the SERZ. Major, minor and trace compounds were performed on all the gas samples whilst isotopic analyses of He (R/Ra) and  $\delta^{13}\text{C}$ -CO<sub>2</sub>,  $\delta^{18}\text{O}$ ,  $\delta\text{D}$  and  $^3\text{H}$  were carried out on selected representative samples. Thermal, fresh and meteoric waters were analysed to define interaction processes between surficial and deep sources. H<sub>2</sub>O is the main component of the fumarolic gases (83-95% wt) while, on the basis of dry gases, two groups have been recognised: i) CO<sub>2</sub>-rich and ii) N<sub>2</sub>-rich gases. Those from the summit area (Fields A, B, C and Sulphur Banks) are CO<sub>2</sub>-rich and have outlet temperatures close to the boiling point. On the other hand, gases from Pu'u O'o and steaming areas are N<sub>2</sub>-rich with temperatures between 46° and 76°C, suggesting strong atmospheric contamination. CO<sub>2</sub>-rich gases exhibit N<sub>2</sub>/Ar and N<sub>2</sub>/Ne ratios (>200) which are significantly higher than those of the air and air-

saturated water. Although no  $\delta^{15}\text{N}$ -N<sub>2</sub> are available, up to 30% by vol. of N<sub>2</sub> can be referred to denitrogenation processes of organic matter. Hydrocarbons contents and their strong positive correlation with non-atmospheric N<sub>2</sub> seem to support this hypothesis. Sulphur species, HF, HCl and HBr were determined by a new analytical procedure based on ion chromatographic technique. SO<sub>2</sub>, H<sub>2</sub>S and S<sub>8</sub><sup>0</sup> concentrations are up to 16, 0.2, 0.01% wt., respectively, while HF, HCl and HBr are only present at a very low amounts such as H<sub>2</sub>, CO and He. The latter do not show correlation with other gas compounds. Low-pH values and high concentrations of SO<sub>4</sub> characterise the fumarolic condensates. 52 trace elements were determined and found at ppb levels. By comparing these values with those of the Hawaiian basalt standard reference BHVO-1, it can be suggested that most of the trace elements derive from fluid-rock interaction and transported mainly as sulphate and chloride complexes, although chalcophile elements can also be dragged as sulphides up to the surface. As already pointed out elsewhere,  $^3\text{He}/^4\text{He}$  and  $\delta^{13}\text{C}$ -CO<sub>2</sub> values suggest a mantle origin of these components.  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values and tritium concentrations on fumarolic condensates indicate a recharge dominated by meteoric water. However, at least four different processes seem to modify the isotopic composition of steam water: i) low-temperature hydration of basaltic glass; ii) disequilibrium evaporation; iii) HT exchange with rock and iv) interaction with gas phases.

#### VPP6 : SUPO09 : PO Chlorine in Volcanic Systems

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Subduction zone volcanoes showing fumarolic activity often display close association of hydrothermal and magmatic systems. Volcanic gases can escape directly, or interact with shallow or deep water systems as the result of structural and permeability contrasts. Such volcanic systems are characterised by the generation of very different phases: high temperature gases in central craters, low temperature distal gas emanations, volcanic encrustations or sublimates, aerosols, mineralised waters. In the context of subduction zones, these phases can be chlorine-rich and are considered to be representative of the volcanic and/or hydrothermal activities. The chemical and isotopic surveys of these potentially dangerous systems are expected to supply fundamental keys to the understanding of the arc volcano structure and evolution. Focusing attention on the chlorine geochemistry, including both elemental Cl contents and Cl isotopic compositions ( $\delta^{37}\text{Cl}/\text{SMOC}$ ), may therefore help to constrain the generation mechanisms and the relationships between these different phases. Chlorine stable isotopes are rarely used in this field of research despite showing a discrepancy between surface and high temperature signatures. A feasibility study has been undertaken into the use of  $\delta^{37}\text{Cl}$  for surveying volcanic activity and understanding the variability of halogen concentrations in the different phases or components with time. La Soufrière de Guadeloupe, French West Indies and Vulcano in Italy, have been chosen as test sites. The first site is a highly hydrothermal system while the second is influenced by both magmatic and hydrovolcanic activities. La Soufrière was chosen for a spatial and temporal survey while on the latter, chosen for its large range of fluid chlorine concentrations and temperatures, a spatial and methodological study was conducted. In Guadeloupe, this study is particularly interesting as gas emanating from the main summit fumarole have suddenly become very acid in 1998. This change in acidity has been accompanied by mild yet persistent fumarolic reactivation with higher temperature, greater gas flux and an increase in the gas S/C ratio. So far neither the hydrothermal perturbation or the incipient magmatic reactivation hypotheses have been confirmed. More than 80 recent and archive samples of hot springs, gases and sublimates (Vulcano) show a large

range of  $\delta^{37}\text{Cl}$  values (-2.28 up to 1.95‰). These values changing temporally (Guadeloupe) and geographically seem also to be related to the collection temperature of the samples (Vulcano). The relationships point to mixing and/or fractionation processes. In some cases, they identify three end-members with specific  $\delta^{37}\text{Cl}$  likely to be meteoric waters, hydrothermal waters and magmatic fluids. Such preliminary results indicate that  $\delta^{37}\text{Cl}$  associated with others tracers (e.g.  $\delta\text{D}$ ,  $\delta^{18}\text{O}$ ,  $\text{pCO}_2$ ) is a promising new tracer of volcanic activity. Acknowledgments : We would like to thank the CRV and the PNRN program for financial support.

**VPP6 : SUpo10 : PO**  
**Temporal Variations in Magma Composition at Merapi Volcano, Central Java: Magmatic Cycles during the Last 2,000 Years of Explosive Activity**

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Merapi volcano (Central Java, Indonesia) has been frequently active during Holocene time producing basaltic and basaltic andesites of medium-K (calc-alkaline) affinity in the earlier stages of activity and high-K (high-K calc-alkaline) magmas from approximately 2,000 years to the present. During this younger period, Merapi volcano has been almost continuously active, thus providing an excellent and rare opportunity to study temporal chemical variations in magma composition throughout the history of an andesite stratovolcano. The geochemical evolution during the last 2,000 years is characterized by systematic cyclic variations, which record a complex interplay of several magmatic processes, such as fractional crystallization and magma mixing, which appear to be ultimately related to eruption rates. The main points can be summarized as follows: (1) The geochemical evolution of Merapi over the last 2,000 years is characterized by the occurrence of magmatic cycles, which last from approximately 300 to 600 years. The cycles begin with the eruption of evolved rock types (56-57 wt.%  $\text{SiO}_2$ ) and end with the eruption of mafic compositions (52-53 wt.%  $\text{SiO}_2$ ). (2) Each magmatic cycle is characterized by high eruption rates following an approximately 150-year-long period of apparently reduced volcanic activity. (3) Fractional crystallization played a fundamental role in generating evolved magma compositions from parental mafic magmas. Radiogenic and oxygen isotope compositions preclude a significant role of crustal contamination in the evolution of magma at Merapi. (4) Low eruption rates in periods of reduced volcanic activity in between consecutive magmatic cycles and the absence of new influxes of mafic magma allow the generation of evolved magma and the development of compositional zonation in the magma reservoir. Magmas erupted during these stages display intermediate compositions reflecting the progressive differentiation of magmas towards andesitic compositions. (5) The onset of a new magmatic cycle, probably because new influxes of mafic magma from depth enter the magma reservoir, results in the eruption of evolved magma at the beginning of a new cycle and a series of eruptive products, that reflect the chemical zonation in the magma chamber. Mixing of primitive with evolved magma in the magma chamber may also account for chemical zonation. Dense mafic magma, at the beginning trapped below relatively light, evolved compositions, is erupted towards the end of such a cycle. (6) Throughout the historical and recent activity (1883 AD to present) similar but apparently shorter cyclic variations than in the stratigraphic record can be observed.

**VPP6 : SUpo11 : PO**  
**15 Days of Continuous Observation of Stromboli Volcano (Italy) in Late September 2000: Magma Replenishment and Weather Dependence of Eruptive Style**

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Stromboli volcano, known for its continuous activity during the last 4000 years, is an island north of Sicily (Italy) with an active zone of 3 main vents. The reason for the permanent activity and the source mechanisms of the different eruption styles are still poorly constrained, but a strong influence of weather and humidity on the volcano has been suggested previously. By combining visual observations with soil humidity measurements and other geophysical data (continuous Radar Doppler observations, seismic monitoring and infrared data) we try to gain some new insight into the eruption processes.

Soil humidity and its impact on eruptive style was qualitatively surveyed by two soil samples per day indicating a decreasing humidity on the volcano surface during the 15 days of observation. Simultaneously with this decrease we observed a change in the eruptive style and overall activity: Activity at crater 2 was dominated by phreatomagmatic explosions during the first three days, successively shifting to magmatic fountains later. This indicates that the eruptive style at Stromboli is influenced by water-magma interaction in the conduit during humid periods. A similar observation was made earlier this year and this type of interaction was previously used to explain the abundance of strong phreatomagmatic explosions occurring at Stromboli between autumn and spring. Besides this weather dependence of the eruptive style an overall increase in activity was observed and also detected by the Doppler Radar and seismicity.

The rising unrest of the volcano and the observation of steady scoria throw accompanied by well audible burst of bubbles out of crater 2 during 5 days suggests a rising lava level in the conduit and the formation of a lava lake inside the crater. The formation of this lava lake was accompanied by a strong increase of eruptive intensity of crater 3, which was nearly quiescent during the first 5 days of our monitoring period. We interpret the occurrence of the shallow lava lake as a sign that a fresh batch of magma has reached the low level storage area of Stromboli. This replenishment event lead to a rise in magma level and to large magmatic fountaining (a fire fountain several hundred meter high was observed by Stromboli residents on 6.9.2000) out of the two main craters at Stromboli.

**VPP6 : SUpo12 : PO**  
**Effects of the 79 AD Vesuvius Plinian Eruption in the Buried Sites of Herculaneum, Oplontis and Stabiae from an Integrated Volcanological, Anthropological and Archaeological Study**

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The interdisciplinary study of stratigraphy, pyroclastic deposits, structure collapses, human remains and objects in the sites buried by the 79 AD Vesuvius eruption allow us to constrain the physical properties of the moving pyroclastic currents and their emplacement and cooling conditions. Evidence from structures indicate that the dynamic overpressure and carrying capability changed from very low

values of the first surge to the moderate-high values of the second surge and the following flow episodes. However local obstacles such as buildings, walls and topographic steps diverted the flow, dampened the turbulence and caused the premature deposition of the flow due to loss of momentum, sudden particle segregation, flow separation and back-flow processes. The comparison of the sites of Herculaneum, Oplontis, Pompei, and Stabiae reveals that the decaying of mechanical and thermal effects with the increasing of the distance from the vent and pyroclastic cloud spreading. Structure collapses, maximum horizontal range of the objects transported by the current and particularly the intensity of the effects on people confirm a peak of energy in the site of Herculaneum, which is only 6 km away from the vent. The study of the human remains both in Herculaneum and in Oplontis consistently with temperature determinations by palaeomagnetic investigations of TRM in tile specimens indicate that the death occurred instantaneously, due to a fulminant shock syndrome for the exposition to a temperature approaching 500°C. However, main differences in the type and intensity of thermal effects confirm their dependence on the different position of the two sites as well as on local factors such as the number and concentration of bodies in the rooms. In both cases the skeletons exhibit hands and feet flexion and contracture due to instantaneous thermally induced contraction (nociceptive or flexion reflex) as well as cases of incipient pugilistic attitude (limb flexure) and carbonisation, which are typical of fire victims. Nevertheless all these features present a maximum occurrence in Herculaneum, while they are less evident in Oplontis and relatively rare in Pompeii. The lack of consistency of TRM results for specimen collected within the chambers of Herculaneum indicates that, locally, the deposit temperature fell very rapidly to ambient conditions likely due to the cooling effects induced by the sudden vapourisation of organic material. These results provide constraints for risk evaluation of the highly populated Vesuvius area as well as of other inhabited active volcanic areas.

**VPP6 : SUpo13 : PO**  
**A Newly Discovered Debris Avalanche Deposit: Rivière des Pluies Breccia, Northern Reunion Island**

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Since several years, debris-avalanches deposits in basaltic volcanoes are described all over the world. The prime works came from Hawaii, with descriptions of giant submarine landslides (Moore J. G. et al., 1989, 1994). Other landslides were also described on Canary Islands by Masson D. G. (1996), and on Reunion Island (Lénat J-F. et al. 1990, Bachelery P. et al., in press). During our works at the Earth Science Laboratory (L.S.T.U.R.) in the University of Reunion, we have discovered a non-identified breccia in a place called 'Le Grand Eboulis'.

The large breccia outcrop located on the northern flank of the Piton des Neiges volcano in 'Rivière des Pluies' riverbed, provides evidence for a landslide origin. This hummocky terrain (block facies) consists of shattered and deformed lava flow and dykes segments with typical jigsaw fractures. The same facies was identified in the river 'Ravine des Patates à Durand' between the gullies 'Ravine Blanche' and 'Ravine Grande Marmite'.

'Grand Eboulis' hummock may result from (1) deceleration of a debris-avalanche in response to a lateral shear or (2) erosion that have revealed this layer in two river beds. It seem to be a proximal facies of debris-avalanche. In a more distal part, one kilometer downstream, blocks are so shattered and scattered that original structures are unrecognisable. This landslide sampled the old formations of Piton des Neiges Volcano, called formations I and II (Billard, 1976), characterised by aphyric basalt, olivines basalt, picritic basalt and plagioclase rich basalt. Formation I is affected by a strong hydrothermal alteration producing secondary minerals such as zeolites, serpentine, chlorites and calcite.

Because we have identified two areas with similar debris-avalanche deposits, two scenarii of deposit can be proposed: In the first scenario, a large debris-avalanche has recovered the former basaltic 'Piton des Neiges' topography. Its deposits are revealed by the rivers incision

('Rivière des Pluies' and 'Ravine des Patates à Durand'). In the second scenario, several small landslides occurred in a close period of time by falls of riverheads cliffs.

Furthermore, in those deposits, we have not identified rocks from the covering differentiated formations III and IV (e.g. plagioclase xenoliths basalt and mugearite). So the landslides may occur by the end of the shield building stage (around: 0.45 My). When our field survey and petrogenetic study will be completed, we may choose between the two scenarios and find the western and upper limits of this landslide(s).

Moore JG, Clague DA, Holcomb RT, Lipman PW, Normark WR, & Torresan ME, *J. of Geophys. Res.*, **94**, 17465-17484, (1989).

Moore JG, Normark WR, & Holcomb RT, *Annual Review of Earth and Planetary Sciences*, **22**, 119-144, (1994).  
Masson DG, *Geology*, **24-3**, 231-234, (1996).

Lénat JF, Labazuy P, *Monographie- Le volcanisme de la Réunion*, 43-114, (1990).

Bachèlery P, Robineau B, Courteaud M, Savin C, *Bulletin de la SGF*, (in press).

Billard G, *Carte Géologique de la Réunion 1/50000*, (1974).

#### VPP6 : SUpo14 : PO

##### Formation of Levées in Pyroclastic Flow Deposits

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Pyroclastic flow deposits sometimes exhibit a particular morphology: the deposit is composed of a lobe with lateral levées and a low central channel (Davies et al., 1978 ; Rowley et al., 1981). Various hypotheses have been proposed for the formation of this morphology : lateral static zones linked to the rheology, drainage of the central part of the deposit, differential deflation after emplacement due to segregation figures, and differential fluidisation of borders during emplacement (Rowley et al., 1981 ; Wilson and Head, 1981). The aim of this study is to understand the formation of such a morphology with the help of laboratory experiments involving granular flows. We show that the channel/levées morphology is due to the dynamics of the flow and that no post-emplacement process is required.

Experimental flows are created by the release at a constant rate of glass microbeads on a rough, wide plane. The flow develops as a finger of granular matter that rapidly reaches a stationary state with constant velocity, height and width. When moving downwards, the front of the flow spreads slightly laterally until it reaches the width of the finger. Far from the front, two borders of fixed granular material appear on the edges of the flow. When the supply stops, the height in the central channel decreases due to the downwards flow of particles, while the height of the fixed borders remains constant. Consequently, the central channel become lower than these borders, corresponding to the levées/channel morphology on the field. Morphology of the flow and its deposit have been measured in each experiment. We show that the morphology is a function of the slope, flux and type of particles used. Working with a range of sizes of particles enhances the amplitude of the morphology by lowering the central channel thickness and increasing the height of the levées. In that case, we observe segregation figures corresponding to field observations: large particles compose the front and the levées, small particles the central channel. Experimental variations with the slope are consistent with field data (Wilson and Head, 1981), with an emphasising of the morphology where the local slope increases. The height of the deposit in the central part and its variations can be interpreted in terms of the thickness of material ( $h_{sup}$ ) which remains on a slope after a flow has passed (Pouliquen, 1999). The height of the levées corresponds to the maximum height reached by the flow on the borders. This particular morphology combining two different heights in the deposit can be interpreted in terms of stability and metastability of a layer of granular material on a slope (Daerr and Douady, 1999).

D.K. Davies, M.W. Querry & S.B. Bonis, *Geol. Soc. Am. Bull.*, **89**, 369-384, (1978).

P.D. Rowley, M. A. Kuntz & N. S. Macleod, *Geol. Sur. Prof. Paper*, **1250**, 489-512, (1981).

L. Wilson & J.W. Head, *Geol. Sur. Prof. Paper*, **1250**, 513-524, (1981).

O. Pouliquen, *Phys. Fluids*, **11**, 542-548, (1999).

A. Daerr & S. Douady, *Nature*, **399**, 241-243, (1999).

#### VPP6 : SUpo15 : PO

##### The Possible Method of Migration of Plinian Volcanic Eruption Hazards

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It is known that explosive Plinian eruptions are typical for volcanoes with the shallow magma chambers, from which the highly viscous volatile-rich lavas rise to the surface with high rate. The recent works of a number of researchers on the modeling of degassing dynamics of magmatic melts responsible for the mode of volcanic eruptions, gave us insight into the reasons of explosive eruptions.

The first stage of degassing is separation of gases dissolved in magma into individual bubbles increasing in size and floating to the upper part of the volcanic chamber. Owing to this process magma can turn here into magmatic foam, a visual example of which are pumices. At the second stage of degassing the destruction of this foam took place resulting in separation of gas from the melt. Both the growth of bubbles and destruction of magmatic foam depend on the magma properties and physical conditions of its degassing. The viscosity is the most essential among magmas properties. The great viscosity of rhyolitic magma can slow down the growth of gas bubbles and retain their high excess pressure. During the rise of such bubbles, magmatic foam with increased internal pressure is formed in the upper part of volcanic chamber. This foam is capable to explosive degassing with its instantaneous transformations into hot clouds of volcanic ash with pumice fragments specific for disastrous Plinian explosive eruptions. Spontaneous disruption of magmatic foam strongly depends on the viscosity of melt forming this foam. The main mechanism of such disruption for viscous rhyolitic melts is the outflow of melt along films between gas bubbles, while for basaltic melts - along the contacts of bubbles (Gibbs Plateau channels). In rhyolitic melts the size of the bubbles increases proportionally to the cube root from the time of melt solidification, while in basaltic melts it is directly proportional to this time. Therefore, magmatic foams from viscous rhyolitic melts contain smaller gas bubbles and their spontaneous disruption and degassing proceed slower as compared to basaltic foams. Delay in degassing of rhyolitic foams can result in their fast explosive disruption, which is commonly realized as disastrous eruptions.

In order to mitigate the Plinian types explosions it is necessary to decrease the lavas viscosity by all means. One of such methods could be throwing crushed limestone down from helicopters right into the volcanic craters, which are about to renew the Plinian explosions. The addition of 10 wt.% of limestone to the rhyolitic melt reduce its viscosity in thousand times.

#### VPP6 : SUpo16 : PO

##### The Evaluation of Volcanic Risk of Campi Flegrei (Italy)

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The volcanological history of Campi Flegrei suggests that the most frequent eruptions are characterised by the emplacement of pyroclastic flow and surge deposits erupted from different vents scattered over a 150 km<sup>2</sup> wide caldera. The evaluation of volcanic risk in volcanic fields is complex because of the lack of a central vent. To approach this problem, we subdivided the entire area of Campi Flegrei into a regular grid and evaluated the relative spatial probability of opening of vents basing on geological, geophysical and geochemical data. We evaluated the volcanic risk caused by pyroclastic flows basing on the formula proposed by UNESCO (1972)  $R = H \times V \times Va$ , where H is the hazard, V is the vulnerability and Va is the value of the elements at risk. The product H x V was obtained by performing simulations of type eruptions centred in each cell of the grid. The simulation is based on the energy cone scheme proposed by Sheridan and Malin (1983), hypothesising a column collapse height of 100 m for eruptions of VEI=3 and 300 m for eruptions of VEI=4 with a slope angle of 6°. Each simulation has been given the relative probability value associated with the corresponding cell. The vulnerability linearly decreases with the

distance from the vent. We made use of the GIS software ArcView 3.2 to evaluate the intersection between the energy cone and the topography. The superposition of the areas invaded by pyroclastic flows (124 simulations for VEI=3 and 37 for VEI=4) was used to obtain the relative vulnerability map of the area. The relative volcanic risk map is obtained by superimposing the urbanisation maps.

Sheridan MF & Malin MC, *J. Volcanol. Geother. Res.*, **22**, 163-197, (1983).

UNESCO, *Document SC/WS/500*, 11 pp, (1972).

## Monday PM Session

## VPP6 : MOPm21 : G4

Cities on Volcanoes on Limestone: Volcanic CO<sub>2</sub> Related Hazards in the City of Rome and Hinterland (Italy)

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Rome was built along the Tiber valley, equally distant from the Colli Albani (CA) volcano to the southeast and the Sabatini volcanoes to the northwest. After WWII, the Roman area has undergone rapid urbanization spreading mostly to the east and to the south, closer and closer to the CA central vent area. Today Rome is a large city with more than 4 millions people living on the volcano. The volcano is quiescent (De Rita et al., 1995) with shallow seismicity (Chiarabba et al., 1994) and local gas emissions (Quattrocchi and Calcara, 1994), mostly CO<sub>2</sub> along main faults, as well as deposition of travertines (Faccenna et al., 1993, 1994). Peri-Tyrrhenian Quaternary volcanism is related to back-arc extension that stretched and thinned the Tertiary orogenic crust of the Italian peninsula. Several are the unique characteristics of this volcanism, the most peculiar of which are the high-potassic chemistry of magmas (Roman Magmatic Province; RMP) and the CO<sub>2</sub> as main gas phase likely related to assimilation of the trusted Mesozoic-Cenozoic carbonatic successions that make up the uppermost 10 km of the crust. Eruption styles, volcanic morphologies and hydrothermalism are conditioned by magma chemistry, volatile content and, considering that most of the RMP volcanoes lie along the coast and above karstic limestones, by Quaternary climatic changes and the presence of substantial hydrogeological systems. The short term volcanic hazards in the Roman area are mostly related to the interplay between residual thermal energy of the CA magma chamber, the CO<sub>2</sub>-rich hydrothermal system and the regional tectonic stress field. Particularly: a) CO<sub>2</sub> and other poisonous gases release in air, ground and superficial water; b) Phreatic activity and sink holes subsidence due to dissolution of carbonates at shallow depth; c) Shallow seismic swarms. In the long term volcanic unrest might be triggered by regional tectonism with potential for phreatomagmatic activity and lahars. A G.I.S. designed for the zonation of the volcanic related hazard in the Roman area is in progress (Giordano et al., in press) and presented.

De Rita D, Giordano G, Rosa C, Sheridan MF, *The Volcano of the Alban Hills, Tipografia SGS, Roma, 267-281, (1995).*

Faccenna C, Funicello R, Montone P, Parotto M, Voltaggio M, *Mem. Descr. Carta Geol. d'It., 49, 37-50, (1994).*

Giordano G, Mazza R, Cecili A, Capelli G, De Rita D, Bigi G, Rodani S, *J. Nepal Geol. Soc. (in press).*

Faccenna C, Lorindo F, Funicello R, Lombardi S, *Quatern. Proceed., 3, 47-57, (1993).*

Chiarabba C, Malagnini L, Amato A, *Bull. Seis. Soc. Am., 84, 295-306, (1994).*

Quattrocchi F, Calcara M, *Mineral. Magaz., 750-751, (1994).*

## VPP6 : MOPm22 : G4

## Carbon Dioxide and Radon Hazards in the Alban Hills Volcanic District (Central Italy)

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The sudden and catastrophic, or slow and continuous, release at surface of naturally-occurring toxic gases poses a serious health risk to people living in geologically-active regions, such as Italy. In particular the continual urban expansion of such large cities as Rome onto the slopes of active/quiescent volcanic complexes has placed densely populated regions at risk of decreased air quality due to the natural release of toxic gases. This decreased air quality constitutes a serious health hazard which can result in dizziness and vomiting at low CO<sub>2</sub> concentrations, death by asphyxiation at high CO<sub>2</sub> or H<sub>2</sub>S concentrations, or the

development of lung cancer due to long-term exposure to radon. To date, this problem has received little attention from local governments due to a lack of knowledge, and it is only after a sudden death or injury due to gas emanations that the public becomes aware of the possible risk of living in an area. In the central Italian region of Lazio alone this has included the death of at least 10 people in the last 15 years, as well as the recent death of thirty cows in 1999 on the southern outskirts of Rome due to CO<sub>2</sub> asphyxiation.

The present paper gives results of a study on the dangerous gas emanations occurring in the Province of Rome (Alban Hill Volcanic District) which combines soil-gas and geological surveys with demographic data via a Geographical Information System (GIS) program, resulting in the creation of a toxic-gas risk-assessment map of the area. This work presents a standardised geochemical and geological approach which can be used by municipal and regional governments for land-use planning in new subdivisions or to resolve health problems in existing residential areas. In the case of the former, areas defined as high risk can thus be zoned for agricultural or parkland use and not for residential development, while for the latter modifications can be made on 'high-risk' existing homes to improve safety or regulations can be enacted to prevent people from sleeping in basements or on the ground floor.

## VPP6 : MOPm23 : G4

## The Investigation of Fumarolic Gases to Forecast Volcanic Activity

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The forecast of eruptions can be considered as the most important task of the study of volcanoes but, in spite of heavy damages derived during the last decades to human lives and properties, this problem does not seem to have produced a sufficient attention from the scientific community.

According to the scanty information arising from the historical record, the most catastrophic volcanic events are related to explosive activities at apparently dormant volcanoes (e.g., Vesuvius AD 79 and 1631, Krakatau 1883, La Pelée 1902, Lamington 1951, Mount St. Helens 1980, Nevado del Ruiz 1985, Pinatubo 1991) so that any attempt at understanding an increase of eruptive probability appears to deserve special efforts in investigating quiescent systems.

Natural phenomena are supposed to evolve at a gradual rate, and some kind of precursor can be expected to precede also apparently abrupt natural events. Volcanoes must be regarded as the surficial part of deeper fluctuating systems, which occasionally can give rise to eruptive phenomena. Because of their nature, gaseous species are readily sensitive to any physico-chemical change at depth, and volcanic systems which behave in closed manner with respect to magma ascent are normally not closed with respect to gases.

In extensional areas, fluid magmas generating basaltic volcanism do not allow the storage of significant concentrations of gaseous species, which are gradually released during the ascent of magmas towards the earth's surface; seismic activities and ground deformations are mainly recorded as short-term forerunners of effusive events. In compressional areas, a large fraction of volatiles can persist even at shallow depth in viscous magmas feeding andesitic or more acidic volcanism, so that important degassing is also expected to occur before any eruptive episode.

Uprising hot magmatic fluids can interact with ground-water, producing vaporization and a pressure build-up. This interaction can represent an important factor in triggering eruptive activities, whose characters strongly depend on the mass balance between the energy output from magma bodies and the water availability.

Sufficient vapour pressures to initiate explosive eruptions are expected when both components are operating, while effusive phenomena are observed for exceeding heatflows,

and substantially hydrothermal activities result from predominating water recharges. Quenching of ascending high-temperature gases is expected as the result of their interaction with shallow aquifers. High pressures inside volcanic systems can be associated to higher extents of quenching, that is to greater discrepancies between equilibrium and observed temperatures.

Chemical disequilibrium appears as a necessary condition, even if not sufficient, for the occurrence of eruptive activity, and resumed activities of quiescent volcanoes are expected to follow conditions of chemical disequilibrium. In order to verify to which extent this 'working hypothesis' can be applied to procedures of volcano surveillance, the data available for a certain number of volcanoes from different tectonic environments, with or without recent eruptive activities, have been considered.

## VPP6 : MOPm24 : G4

## Fluid Phase Monitoring at El Chichon Volcano, Chiapas, Mexico: Compositional Changes Related to the Activity of the System

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The strong plinian eruption occurred at El Chichon volcano (Chiapas, Mexico), commenced in March 1982, caused the complete destruction of the villages Volcan, Tanchichal, Francisco Leon, Guayabal, Trinidad, Naranjo, Yaspac, located at the foothill of the north-western and south-eastern flank of the volcanic edifice. More than 2000 people died. Until that, the activity of El Chichon volcano, discovered only in 1928 during petroleum explorations, was totally unknown. In 1983 scientists started investigating the area, collecting rock, water and gas samples in order to both re-construct the eruptive history of the volcano and study the chemical characteristics of the fluids interacting with the magma body.

During 1997-2000 a systematic sampling of the crater lake and fumarolic and hot acid spring discharges, which characterise the 1 km wide summit crater, has been carried out and detailed chemical analyses for major, minor and trace compounds have been performed. In particular, the annual monitoring of the fluid phases of the crater has permitted to control the behaviour of chemical parameters which are, in general, particularly sensitive to changes in the status of the volcanic system and the surrounding environment. The aim was the study of the temporal evolution of the volcanic apparatus.

The chemical composition of both waters and gases from the crater has evidenced strong fluctuations in the period of observation, suggesting that rock-fluid interactions may have been modified in time. The crater lake, characterised in the 1983-1997 period by very high salinity (up to 33,000 mg/L), especially due to Ca, Na, Cl and SO<sub>4</sub> contents, showed a sharp decrease in Na and Cl in 1998-1999 (more than two orders of magnitude), followed by a slight increase of the same compounds in the year 2000 (one order of magnitude). SO<sub>2</sub>/H<sub>2</sub>S ratio together with H<sub>2</sub> and CO contents in the gas phase from fumaroles and hot springs, are marked by a similar time pattern.

These compositional changes seem to suggest that, despite a general lowering of the hydrothermal activity after the great energy release due to the eruption of 1982, the chemical parameters of the fluids at El Chichon volcano apparently follow a sort of 'pulsing' trend. In this situation complex processes of interaction between volcanic activity and climatic conditions have to be evaluated.

## VPP6 : MOPm25 : G4

## What is Happening at the Depth of a few Hundred Meters at Stromboli

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Breaking of metric bubbles at the top of a magma column is observed during most basaltic eruptions: it is called 'gaspiston' activity during hawaiian eruptions or explosions for strombolian volcanoes. Because these bubbles are the trademark of basaltic activity, one needs to understand their behaviour both when they arrive at the surface and when they formed at depth. By combining acoustic measurements at Stromboli with a model for the sound generation, the bubble length and radius as well as its overpressure have been estimated at the vent. Here, acoustic measurements were recorded at Stromboli in 1992 and 1997 and bubble characteristics are obtained. Because bubbles are significantly overpressurised (around 0.03 MPa in 1992 and 0.004 MPa in 1997) when they break at the top of the magma column, they are also overpressurised when they leave the shallow magma chamber.

Here, simplified equations for the rise of an overpressurised bubble show that such a bubble oscillates while rising. Viscous forces on the magma column above the bubble tends to damp its oscillations while the decrease in the external pressure field as the bubble rises enhances oscillations. The change in volume of the rising bubble pushes the magma column up and down, vigorously enough to produce sound waves of low frequency (bubble volume mode around 0.5 Hz). Furthermore, the initial oscillations of strombolian bubbles are strong enough to produce gravity waves at the surface of the magma column (sloshing waves of 1-3 Hz), which can be detected acoustically.

The model for bubble rise predicts that a precursory peak in acoustic pressure, i.e. ahead from the explosion itself, should occur simultaneously both around 0.5 Hz (bubble volume mode) and 2 Hz (sloshing modes) when the bubble starts its rise in the conduit. First, the amplitude of the precursory peak in acoustic pressure (0.11 Pa in 1992 and 0.005 Pa in 1997) measures the initial overpressure in the bubble. Second, the time delay between the precursory peak and the explosion itself corresponds to the time needed for a bubble to rise from the magma chamber to the surface.

Results shows that a strombolian bubble has an initial length of one fourth of its radius (0.9 m) for an initial overpressure of 11 MPa (in 1992) and 4 MPa (in 1997). The depth of large bubbles formation, i.e. the shallow magma chamber, has also migrated down between 1992 (at 70 m) and 1997 (at 300 m), in agreement with seismic observations. Although Stromboli volcano is in steady-state, there is some significant variation over several years for the source of Strombolian activity.

## VPP6 : MOPm28 : G4

## Estimation of Physical Parameters of Vulcanian Eruption of the Soufriere Hills Volcano, Montserrat

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Since the beginning of the eruption of the Soufriere Hills Volcano in July 1995, two series of periodic vulcanian explosions occurred: 13 between 4 and 11 August 1997, and 75 between 22 September and 21 October 1997. Each sequence followed a major collapse of the andesitic dome. Vulcanian explosions were short-lived events with explosion seismic (LP) signals lasting a few tens of seconds. The beginning of each explosion consisted of the discharge of multiple jets of debris; several tens of jets are visible in each explosion before they are hidden by the volcanic plume. Then jets coalesced to form a convective plume. After about 15-20 seconds, pumice flows were generated all around the volcano by fountain collapse, with typical mean runout distances between 3 and 6 km. These pyroclastic flows were accompanied by the rise of co-ignimbrite plumes. Our study focuses on three vulcanian explosions documented by video on 6 October at 17:45, on 7 October at 16:03 and on 9 October at 12:32. Each eruption discharge respectively  $1.8 \times 10^9$ ,  $2.8 \times 10^9$  and  $1.8 \times 10^9$  kg of magma, sending convective plumes 12.2, 13.7 and 12.2 km into the

atmosphere. The high-frequency pyroclastic flow signal appeared respectively 5, 24 and 20 s after the explosion signal. The progress of individual jets was traced from video, every 0.5 s, in order to construct height-time curves which were then extrapolated back to determine vent exit time and exit velocity of each jet. To do so, two fits were carried out. The first consisted of an empirical quadratic fit. The second used an eruption jet model. In both case, estimated exit velocities are quite similar, ranging from 40 to 140 m/s. The jets occurred in groups several seconds apart with exit velocities increasing with time. With estimated exit velocities, modelling allows us to estimate water contents involved in each explosion. The values ranged from 0.5 to 1.5 wt%. Assuming that only water contained in the vesicles contributed to the explosions, gas pore pressures at fragmentation increased with time up to 12 MPa, as the fragmentation surface descended the conduit. The brutal decompression of the conduit by dome collapse led to the fragmentation of the pressurised magma and to the beginning of each series of explosions. Our study shows the discontinuous aspect of vulcanian explosions with the ejection of many jets of debris separated by several seconds. During each explosion, the intensity of the explosions increased over the first 10 s. Progressively more and more gas was involved in individual jets. This implies that the pressurised volcanic conduit was partly, or totally emptied by progressively deeper and deeper fragmentation.

VPP6 : MOPm29 : G4  
Geology and Volcanic Hazards of El Misti Volcano Near the City of Arequipa, Peru

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Approximately 750,000 people live at risk in the city of Arequipa whose centre lies 17 km from the summit (5820 m asl.) of the active Misti stratovolcano. The composite edifice comprises a 'modern Misti' stratocone <0.11 Ma old which has been built up to the East South East and partially overlaps an 'old Misti' stratovolcano (~0.83 - >0.11 Ma; Thouret et al., 2000).

The eruptive history and behavior of 'modern Misti' indicates that: (1) Seven eruptive periods have built up two cones during the past 110,000 years, resulting in an average eruptive rate of  $-0.6 - 0.7 \text{ km}^3/\text{ka}$ . (2) Several episodes of growth and destruction of andesite domes have triggered dome collapse avalanches and block-and-ash flows. They have alternated with explosive events which emplaced pumice-, scoria- and ash-flow deposits, and tephra-fall and surge deposits. (3) Nonwelded, dacitic and rhyolitic ignimbrites may have led to the formation of a collapse caldera on the first stratocone between ca. 48,640 and >38,300 yr BP and a summit caldera on the second stratocone between ca. 13,640 and 11,280 yr BP. High Self Potential anomalies suggest the boundaries of the collapse caldera. Structural unconformity, ignimbrites, and a minor SP anomaly point to the summit caldera. (4) Tens of pyroclastic flows and at least twenty tephra falls were produced by explosive eruptions during the past ca. 49,000 years. On average, ash falls have occurred every 500 to 1500 years and pumice falls every 2000 to 4000 years; (5) Recent input of andesite magma triggered scoria flows with phreatomagmatic bombs between ca. 13,640 and 8,140 yr BP, the ca. 2000-yr-old subplinian tephra-fall and pyroclastic flows with banded pumices, and historical ashfalls.

Considerable hazards posed to the densely populated area of Arequipa are portrayed in three hazard-zone maps based on explosive episodes that occurred 550 years ago, ca. 2000 years ago, and ca. 13,640 - 11,280 years ago. The first hazard-zone map, based on low magnitude/high frequency event like the AD 1440 - 1470 ashfall, represents expected effects of the most probable eruption of Misti. The second hazard-zone map depicts areas to be affected by an eruption similar to the ca. 2000-yr-old episode whose magnitude (volume of  $\sim 0.75 \text{ km}^3$ ) and frequency (2000 - 4000 years) were relatively moderate. The third hazard map portrays areas likely to be affected by ignimbrite-forming eruptions such as the ca. 34,000 - 33,000 and ca. 13,640 - 11,280 yr BP eruptive episodes. Large-scale eruptions may recur every 7,000 to 15,000 years on average.

Thouret JC, Finizola A, Suni J, Fornari M & Legeley-Padovani, Submitted to *Geological Society of America Bulletin*, (2000).

## VPP6 : MOPm30 : G4

## Piton de la Fournaise Volcano, Reunion Island, Starts a New Cycle of High Eruptive Activity

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Piton de la Fournaise volcano, which is one of the most active volcanoes in the world, had during the last century a mean frequency of about 1 eruption per year. This makes it an excellent volcanological laboratory, to develop and to test within a reasonable time span new methods to detect volcanic precursors. Two cycles of low eruptive activity are known within the last 50 years, between 1967 and 1972 and between 1992 and 1998, the last quiet period lasted 5 1/2 years. In between, high eruptive periods occurred, as in 1985-1987 with 5 eruptions per year.

In March 1998, a new period of high eruptive activity started :

- 1998 (2 eruptions) March 9 to Sept 21 March 12 to April 2  
- 1999 (2 eruptions) Jun 19 to July 31 Sept 28 to Oct 23  
- 2000 (3 eruptions) Feb 14 to march 4 June 23 to July 30  
Oct 12 to Nov 13

1998 was characterised by two eruptions, one exceptionally long lived eruption which lasted 6 1/2 months and a separate eruption within this period, with a more primitive magma composition. The March 9 eruption was preceded by a long-term increase of seismicity over 9 months and ground deformations and an unusual long seismic crisis of 36 hours. The volume of erupted magma was estimated between 50 to 60x10<sup>6</sup> m<sup>3</sup>.

In 1999, two eruptions occurred, with no significant long-term precursors and seismic crisis duration of about 1 hour. Both eruptions were characterised by an initial short eruption phase, where aa type lava flows were put in place within less than 12 hours. Several days after that, mainly pahoehoe type lava flows emerged from vents 1.2 and 4 km away from the initial ones, accompanied by a large increase of tremor. Erupted volume of about 1.5x10<sup>6</sup> m<sup>3</sup> were small and no important craters were formed.

The year 2000 was characterised by 3 eruptions with high fountain activity during several weeks and formation of 20 to 30 m high and up to 100 m large craters. The total erupted volume is estimated between 5 and 10x10<sup>6</sup> m<sup>3</sup>. All eruptions had long-term precursors in form of tiltmeter and extensometer variations, important pre-eruptive seismic activity and significant radon emanations before eruptions. During eruptions, an unusual seismic activity persisted.

## VPP6 : MOPm31 : G4

## Application of Non-Conventional Techniques for Magnetic Monitoring of Active Volcanoes

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The structural heterogeneity and the dynamics of the plumbing system of each volcanic edifice can strongly condition typology and characteristics of the precursory signals of eruptions. Traditionally, ground deformations and seismic activity studies are used to detect such precursory signals. However, both methods point out local phenomena such as a rupture along a fault plane or local

# VPP6

## Volcanic Hazards: Monitoring, Prediction and Mitigation

deformations along a fissure system. These techniques can be usefully supported, for monitoring volcanic activity, by the magnetic method that integrates the effect of a phenomenon over a large volume. Also in the absence of local phenomena, such as an earthquake or a fracture opening, the modifications within the volcanic edifice of the stress field or of the thermodynamic state induce variations in the magnetization of rocks. Variations of the magnetic properties of rocks generate a wide variety of signals which may also appear a long time before an eruption. The characterization of these signals can be a useful instrument both for improving the monitoring of active volcanoes as well as developing a greater understanding of the pre-eruptive mechanisms which produce them. Our laboratory has been developing methods, hardware and know-how for the automated acquisition and management of data simultaneously acquired at a variety of remote magnetic stations. In order to provide a basis for short-term decision-making in the forecasting and control of volcanic activity linear and non-linear inversion techniques for the real-time processing of data have also been implemented. The developed system is entirely automated between the stages of data acquisition and processing. Achievement of these objectives should make data processing in real time easier reducing the delay between observation and interpretation and thereby improving the efficiency of volcano monitoring.

### VPP6 : MOp32 : G4 Combined Discrete and Continuous Gravity Observations at Mt. Etna

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Systematic investigation of discrete gravity measurement has been continued at Mt Etna since 1986. Since then the most efficient geometry for an extended array for studying volcano dynamics and forecasting eruptions has been sought. The network covers now an area of about 400 km<sup>2</sup> with 74 stations 0.5 to 3 km apart. It has allowed mass redistributions occurring at depths ranging between about 8 km b.s.l. and a few hundred meters below the surface to be detected (Budetta and Carbone, 1998; Budetta et al., 1999). One of the main drawback of repeated network monitoring is the lack of information on the rate at which the volcanic processes occur. Also a common problem on active volcanoes is snow coverage which makes gravity changes on the summit zone not identifiable on a timescale of less than 6 months during the winter time. If one also considers the need to reduce the exposure of personnel in active areas, the importance of improving the possibilities of continuous gravity monitoring appears clear. Continuous microgravity studies at active volcanoes have been scarcely made in the past because of the logistic difficulties of running them in places where the conditions are far from the clean, ideal laboratory. However, thanks to technological improvements in recent years, we have developed an experimental setup for typical field stations in the active volcanic environment and since 1998 three continuous gravity stations have been recording on Mt Etna of which two are 1 and 2 km far from an active Etna crater respectively. These stations acquire at 1 datum/min sampling rate and thus each furnishes a huge amount of data also because several parameters (up to 7) are acquired simultaneously. Therefore, an advanced software which allows these large data sets to be analysed quickly and with a high level of automation has been designed under LabVIEW<sup>®</sup>. After removing the Earth Tide and the effect of tilt changes from the data, the correlation of the residual gravity sequences with simultaneous recordings of meteorological parameters acquired at each station has been analysed. We have found that, over certain frequency ranges, instrumental effects driven by meteorological parameters are strong and meter-specific. Thus they must be removed by means of case-by-case experimentally assessed transfer functions. Once the meteorological effect has also been removed, continuous gravity changes are within 10 µGal of gravity changes assessed simultaneously by discrete relative observations at sites very close to the continuous stations. This study proves the combined use of discrete and continuous gravity observation by spring gravimeters at active volcanoes to be a valuable tool both for the study of the internal plumbing of an active volcano and for surveillance purposes.

Budetta B & Carbone D, *Bull. Volcanol.*, **59**, 311-326, (1998).  
Budetta G, Carbone D & Greco F, *Geoph. J. Int.*, **138**, 77-88, (1999).

### VPP6 : MOp33 : G4 INSAR Monitoring of Evolution of Deformation at Krafla Volcano (North Iceland), 1992-2000

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Krafla volcano (North Iceland) last underwent a rifting episode between 1975 and 1984. Monitoring of the deformation at the volcano carried out after the rifting episode reveals that the ground above the volcano has undergone deflation after 1989. ERS SAR data acquired between 1992 and 2000 allows us to measure the deformation occurring at the volcano for the equivalent time period. Deformation measured by SAR interferometry at Krafla is composed of two different patterns. Two linear U shaped fringes extend to the North and South of the volcano. The volcano area itself is marked by a set of circular fringes which extends 10 km from the eruptive center. From 1992 to 1998, the measured deformation rate is constant at Krafla, reaching 2.1 cm/y in the radar line of sight. For the 1998 to 2000 period, the measured deformation rate decreases markedly at Krafla. Analytical mechanical modeling has been successfully used to explain the observed fringe pattern. Our best fit numerical model is composed of a set of three horizontal planar structures. The central structure corresponds to a flat magma chamber at 3 km depth. To the North occurs a shallow 100 m wide sill (or dyke head) at 1.5 km depth and to the South a 4 km wide sill at 3 km depth. All three structures undergo contraction. Our model shows marked discrepancies with that of other authors, in particular with respect to the structures North and South of the volcano. Of particular interest is the distinction in depth and width between these two structures and the resulting asymmetry with respect to the magma chamber. Also, the high number of interferograms generated and the time span covered gives us a very good insight of the evolution of the deformation at the volcano. It appears, from our data, that the deformation currently occurring at Krafla, over a decade after the rifting episode, is more the result of thermal contraction of magma accumulated during the rifting episode than a continuation of spreading movements.

### VPP6 : MOp34 : G4 The Application of a Long Range Laser Scanner for Monitoring Volcanic Activity on Mount Etna

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Between 22nd and 25th October 2000, a new type of surveying instrument was used on Mount Etna to survey parts of the summit region. The 3DLM LR1 Riegl Laser scanner system can measure distances ranging from 2 - 2000 m with an accuracy of ±25 mm in typical conditions on Mount Etna. Beam divergence is approximately 1.2 mrad (i.e. 12 cm beam width per 100 m range), and the scanning range is 150 degrees vertical by 360 degrees horizontal. The scanning rate is 1 - 10 / s depending on reflectance and range. The LR1 is powered by a 12V battery and data are transferred to a data logger or PC using a standard RS232 serial link. The LR1 weighs 31 kg. The system can be used for continuous or pulsed laser emission. For pulsed laser emission, the laser is only turned on when sending each pulse and provides eye safe operation. When used in continuous mode, there is less drift and more stability in distance and intensity measurements. Using the Riegl LPMSCAN software, range and distance images are created on the laptop screen as scanning takes place. During the survey, we assessed the practical operating limitations of this type of equipment. 3D Laser Mapping Ltd have developed software for this system and effective post processing software allowed sufficient data for the creation of a digital terrain model even when there was partial obscuration of the field of view by cloud and volcanic gas.

The trials have proved that the 3DLM LR1 instrument is an effective tool for monitoring volcanoes from distances up to 2000 m. The system was also capable of measuring reflective intensity, and this was shown to be a function of surface textures.

The only limitation of the equipment was that it cannot penetrate through mist and volcanic gas. However, this is true of all other conventional surveying methods. Overall the instrument was proven to be portable and practical for use in volcano monitoring.